Calhoun: The NPS Institutional Archive
DSpace Repository

Theses and Dissertations 1. Thesis and Dissertation Collection, all items

1948

# An investigation of the relative importance of those variables affecting the travel of a vessel at launching

Rourke, Robert A.; Slaughter, Robert H.; Rourke, Robert A.; Slaughter, Robert H.

Massachusetts Institute of Technology

http://hdl.handle.net/10945/6466

*Downloaded from NPS Archive: Calhoun*

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

http://www.nps.edu/library

# AN INVESTIGATION OF THE RELATIVE IMPORTANCE OF THOSE VARIABLES AFFECTING THE TRAVEL OF A VESSEL AT LAUNCHING

ROBERT A. ROURKE
ROBERT H. SLAUGHTER, JR.

Library
U. S. Naval Postgraduate School
Monterey, California

Mont 219
8854

Postgraduate School.
U. S. Naval Academy,
Annapolis, Md.

# AN INVESTIGATION OF THE RELATIVE IMPORTANCE OF THOSE VARIABLES AFFECTING THE TRAVEL OF A VESSEL AT LAUNCHING

By

ROBERT A ROURKE
Lieutenant, U.S. Navy
B.S., University of California
1942

ROBERT H. SLAUGHTER, JR.
Lieutenant, U.S. Navy
B.S., Webb Institute
of Naval Architecture
1942

Submitted in partial fulfillment of
the requirements for the degree of
Master of Science
in
Naval Construction and Engineering
from the
Massachusetts Institute of Technology
1948

Thesis
[illegible]

Cambridge, Massachusetts,

May 20, 1948

Professor W. S. Newell

Secretary of the Faculty,

Massachusetts Institute of Technology,

Cambridge, Massachusetts

Dear Sir:

In accordance with the requirements for the degree of Master of Science in Naval Construction and Engineering we submit herewith a thesis entitled "An Investigation of the Relative Importance of Those Variables Affecting the Travel of a Vessel at Launching".

Respectfully,

# ACKNOWLEDGEMENT

The authors wish to express their appreciation to those professors whose help was of such great value in the preparation of this thesis, Professor E. C. Holtzworth, Professor G. C. Manning, and Professor W. W. Robertson for assistance on launching details, and to Professor R. D. Douglass for his great help in preparation of the charts.

We also wish to express our deep appreciation to Captain W. McL. Hague, USN, under whom we served, and whose keen interest in the details of launching the USS ALABAMA, USS SHANGRI-LA, and other vessels, inspired us to pursue the subject as a major interest.

# TABLE OF CONTENTS

Page

SUMMARY . . . . . . . . . . . . . . . . . . . . . . . . . . . 1

INTRODUCTION . . . . . . . . . . . . . . . . . . . . . . . . . 4

PROCEDURE . . . . . . . . . . . . . . . . . . . . . . . . . . 7

Chart I . . . . . . . . . . . . . . . . . . . . . . . . 12

Chart II . . . . . . . . . . . . . . . . . . . . . . . . 13

Chart III . . . . . . . . . . . . . . . . . . . . . . . 14

Chart IV . . . . . . . . . . . . . . . . . . . . . . . . 15

Chart V . . . . . . . . . . . . . . . . . . . . . . . . 16

DISCUSSION OF RESULTS . . . . . . . . . . . . . . . . . . . . 17

Curve I . . . . . . . . . . . . . . . . . . . . . . . . 18

Curve II . . . . . . . . . . . . . . . . . . . . . . . . 19

Curve III . . . . . . . . . . . . . . . . . . . . . . . 21

Curve IV . . . . . . . . . . . . . . . . . . . . . . . . 23

Curve V . . . . . . . . . . . . . . . . . . . . . . . . 24

Curve VI . . . . . . . . . . . . . . . . . . . . . . . . 26

CONCLUSIONS AND RECOMMENDATIONS . . . . . . . . . . . . . . . 27

Curve VII . . . . . . . . . . . . . . . . . . . . . . . 30

APPENDIX . . . . . . . . . . . . . . . . . . . . . . . . . . 31

General Equations . . . . . . . . . . . . . . . . . . . 32

Table of Symbols . . . . . . . . . . . . . . . . . . . . 32

Curve VIII . . . . . . . . . . . . . . . . . . . . . . . 33

Development of Nomographic Charts . . . . . . . . . . . . 38

Development of Chart I . . . . . . . . . . . . . . . 38

## TABLE OF CONTENTS

Page

Development of Chart II . . . . . . . . . . . . . . . . . 39

Development of Chart III . . . . . . . . . . . . . . . 40

Development of Chart IV . . . . . . . . . . . . . . . . 42

Development of Chart V . . . . . . . . . . . . . . . . 43

Table I . . . . . . . . . . . . . . . . . . . . . . . . . 46

Table II . . . . . . . . . . . . . . . . . . . . . . . . 47

Table III . . . . . . . . . . . . . . . . . . . . . . . . 51

Table IV . . . . . . . . . . . . . . . . . . . . . . . . 52

Table V . . . . . . . . . . . . . . . . . . . . . . . . . 53

BIBLIOGRAPHY . . . . . . . . . . . . . . . . . . . . . . . 56

# SUMMARY

The object of this thesis is to determine the relative importance of those variables affecting the travel of a vessel at launching and to devise a rapid means of determining the point of ultimate travel by use of nomographic charts.

Since the functions of the variables which influence the ultimate travel of a vessel at launching are discontinuous, no single formula can be written that will yield the ultimate travel in a single solution. However, a recursion formula used in a step-by-step computation similar to those found in electrical engineering will yield an approximate curve of travel versus velocity, ultimate travel being denoted by the point at which the velocity becomes zero.

Inasmuch as the tediousness of the step-by-step method of calculation varies directly as the number of steps, but the accuracy also increases with the number of steps, a quick method of performing the operations is desirable. The five nomographic charts developed in this thesis accomplish this. There is no single chart that will solve the problem, since there exists no single equation able to do so. However, the charts have been found to reduce the time normally required by as much as four or five times, and thus are considered by the authors to be a quite satisfactory

method of solution. The method of construction of the nomograms devised in this thesis is found in the APPENDIX. It must be remembered that the accuracy of these charts in determining the point of ultimate travel cannot be greater than that of the assumed coefficients.

The results and conclusions have been obtained by successive launching calculations of a hypothetical ship having the same hull form as an ESSEX class aircraft carrier. The physical construction and peculiarities of the ways are those of the battleship ways in the Norfolk Naval Shipyard, since these are standard ways and the authors are familiar with their construction. By changing one variable at a time and holding all others constant, the families of curves found in the RESULTS were plotted. From these curves the authors conclude that: the net chain drag force has the greatest effect upon ultimate travel; the resultant increase in ultimate travel caused by a delay in the point of pickup of chain drags is less than the delay in the point of pickup; a change in the coefficient of grease friction (thus atmospheric temperature on the day of launching) or a moderate change in the combined weight of the vessel and cradle has little effect upon the point of ultimate travel; and a variation in the predicted height of tide has very little effect upon the point of ultimate travel.

The estimate of water resistance was obtained by using the curve of Keith's Coefficient, "C", of Water Resistance as found in Reference [1]. For comparison, a modified curve of Keith's Coefficient, "C", was constructed (Curve VI), keeping the area under the curve equal to that under the standard curve but increasing the float-off or 100% buoyancy value. Two calculations were made, one using the standard "C" curve, one using the modified curve. There was a discrepency of only twenty feet travel, indicating that when large drag forces are used, the shape of the "C" curve is somewhat immaterial. However, this float-off value of Keith's Coefficient "C" becomes increasingly important in determining the point of ultimate travel as the interval of completely waterborne travel is increased. It is, therefore, recommended that further investigation be made to determine more accurately the float-off or 100% buoyancy value of Keith's Coefficient, "C", of water resistance where this curve is to be used for launchings involving small net chain drag forces.

# INTRODUCTION

More than once in the history of the art and science of shipbuilding, the person charged with the problem of launching a large vessel into restricted waters has suddenly realized that his knowledge of the effect of each of the variables involved on the ultimate travel is quite meagre. Generally, he has been unable to find an evaluation of these effects in the literature on launching.

In our modern text books on this subject, there are shown methods of analysis of launching data, but these presuppose that the vessel is already overboard. The launching designer must make his analysis before the vessel is waterborne.

Of the variables affecting ultimate travel, the following are considered of greatest importance:

1. Actual displacement of the vessel at the time of launch.
2. Coefficient of grease friction.
3. Coefficient of chain drag friction.
4. Weight of chain drags.
5. Point of drag pickup.
6. Height of tide.
7. Magnitude of water resistance.

Each of these variables has an effect upon the ultimate travel of the ship, some much greater than others. Those whose effect is relatively insignificant should be discarded for preliminary calculations. However, due to a general lack of literature on the subject to date, it is not known which variables to discard and which to consider seriously.

In general, it is found most feasible to consider that all these variables will combine in any single launching in at least two ways. They may all combine so that the travel will be a maximum, or so that it will be a minimum. If the maximum combination does not allow the vessel to travel too far or to strike the opposite shore, and if the vessel safely clears the way ends with an acceptable margin, the combination is deemed satisfactory, or at least, safe. Any other combination of these variables leads to a refinement in estimating total travel.

Any single calculation for total travel is tedious (an example is given in Table II in the APPENDIX), because it must be done as a step-by-step calculation. No equation yet devised will yield total travel from a given set of variables and from a single solution of the equation. Since the accuracy of the result is a direct function of the number of steps used, a nomogram quickly suggests itself as a rapid means of performing this step-by-step calculation.

In summarizing the considerations of the problem, it might be said that the ship must be transferred from the ways to the water, safely clearing the way-ends and coming to an economically short stop. It must be stopped before striking the opposite bank, and quickly so, to minimize the time required for the tugs to take it in tow and berth it. Also, a short run facilitates chain drag recovery and reduces the cost of the drag roadway installation. However, a long run is desirable to reduce cost of drag installation, to reduce chance of snapping drag wires, and to preclude any possiblility of the drags' preventing the vessel from clearing the ways without having wire tension draw it back up to the way ends. '

There are several methods of calculation presently employed. The Tobin method of integration has been proposed [2], but tends to be cumbersome. The energy equation is commonly used as well as the force equation. All of these methods are tedious unless a nomogram, or "alignment chart" is employed to reduce the number of steps.

It is the purpose of this thesis to develop such a nomogram, or series of them, and with their aid to analyze a launching rather exhaustively to determine the effects of the variables involved.

# PROCEDURE

The procedure in estimating the ultimate travel is based on the "force equation" of Newton,

$$F = Ma \tag{1}$$

By integration, we get an expression

$$V_2^2 = \frac{1}{e^Q}\left[V_1^2 + \frac{CF_1(e^Q - 1)}{B^{2/3}}\right] \tag{2}$$

Where

$$e^Q = e^{\frac{2gK}{W}(S_2 - S_1)} \tag{3}$$

B = Average buoyancy over the increment, in tons

C = Keith's water resistance coefficient

$F_1$ = Net downways force, in tons, exclusive of water resistance

$V_2$ = Velocity at the end of a given increment of travel, in ft./sec.

$V_1$ = Velocity at the beginning of a given increment of travel, in ft./sec.

Since the variables involved come into play at various times, this equation must be applied in a step-by-step manner, getting one value of $V_2^2$ from the previous value of $V_1^2$.

We find $V_2{}^2$ by using nomographic charts. Chart I is entered first to obtain the value of Keith's coefficient, "C". Next, with "C", "W", "B", and the increment of travel under consideration, enter Chart II to obtain $e^a$. ("e" = Napierian logarithm base)

To obtain the resultant downways force, exclusive of water resistance, we use Chart III, entering with the known or assumed variables (W-B), $f_g$, D, $f_d$. Where;

$f_g$ = Coefficient of grease friction

$f_d$ = Coefficient of chain drag friction

D = Weight of chain drags

We read the value of $F_1$ on its scale.

Next, we obtain the value of $\frac{F_1 C}{B^{2/3}}$ from Chart IV, by entering with values of "C" and "$F_1$", from Charts I and III respectively, and "B", which is known from the buoyancy curve.

The last step is to enter Chart V with the value of $\frac{F_1 C}{B^{2/3}}$ from Chart IV, the velocity at the beginning of the increment of travel under consideration, and the value of $e^a$ obtained from Chart II. The value of $V_2{}^2$ is read, its square root taken, and thus we have the velocity of the vessel at the end of the increment in question. The foregoing procedure is followed, step by step,

until a negative value of $V_2^2$ is reached. The vessel stops in this last increment.

An approximation to the actual ultimate point of travel is made by straight line interpolation between the last positive value of $V_2^2$ and the first negative value. Where this straight line crosses $V_2^2 = 0$ is the ultimate point of travel.

Another method also can be used to determine the end point of travel. If we set $V_2^2 = 0$ in equation (2) and solve for S', the distance between the point of travel of the last positive value of $V_2^2$ and $V_2^2 = 0$, we get

$$S' = \frac{WC}{2gB^{2/3}} \operatorname{Log}_e \left[ 1 - \frac{B^{2/3} V_1^2}{F_1 C} \right] \qquad (4)$$

The accuracy of this last method is not considered justified, however, and the straight line interpolation is used in this thesis.

To use the charts, certain data are required. These include:

1. Buoyancy curve versus travel (generally drawn to determine way-end pressures, and based on weight of vessel alone), declivity of ways, height of tide, position of center of gravity of vessel and cradle, point of dropoff, etc.

2. Assumed values of
    a. Coefficient of grease friction, $f_g$
    b. Coefficient of chain drag resistance, $f_d$
    c. Curve of water resistance coefficient versus percent buoyancy afloat.
    d. Point of travel at which chain drags are picked up.
    e. Height of tide.
    f. Number and weight of chain drag clumps per side
    g. Size of increments of travel to be used in step-by-step velocity calculations

The assumptions made in using the force equation include the following:

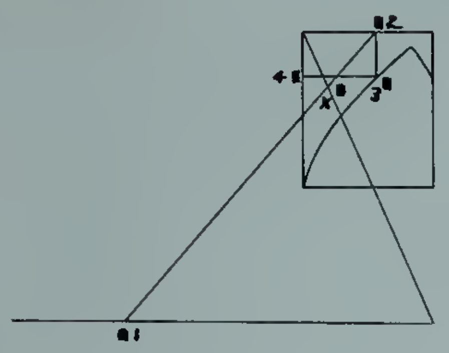
1. Drag resistance coefficient is defined as ratio of the actual drag wire pull to the drag weight. Thus the "coefficient of friction" is modified by the angle of the wire relative to the ground, and acceleration of the drag itself. This angle is very small, however, and the discrepancy between "drag resistance coefficient" and "drag coefficient of friction" is not great.
2. Average buoyancy is used for the entire increment of travel and is assumed to have a constant value throughout the increment. Thus, the values of "C" and "$F_1$" are constants for each increment.

3. Floatoff, rather than dropoff, is assumed; thus no dissipation of energy is considered due to the bow's dropping off of the way-ends.
4. The cradle is assumed self buoyant, but its weight is included in ship's weight because it must be accelerated at the same rate as the ship itself.
5. Keith's curve of "C" versus "% Buoyancy afloat" is assumed as a basis for water resistance chiefly because it is a standard which is available in a commonly used textbook [1]. This curve agrees closely with analyses of the launching of USS TARAWA and USS SHANGRI-LA.
6. All forces which accelerate or decelerate the vessel are assumed to act in the line of motion of the center of gravity of the ship and cradle. The true angle between lines of action of these forces and the tangent to the path of the center of gravity of ship and cradle is very small.

The design of Chart III provides for no camber of ways, and for 9/16" declivity. See APPENDIX, Page 42, for the method of plotting the coefficient of grease friction scale when a declivity different from 9/16" is used. In the event cambered ways are used, it is advisable to calculate the retarding force due to grease friction with a slide rule.

# CHART I

## — TO DETERMINE VALUE OF KEITH'S COEFFICIENT "C" —



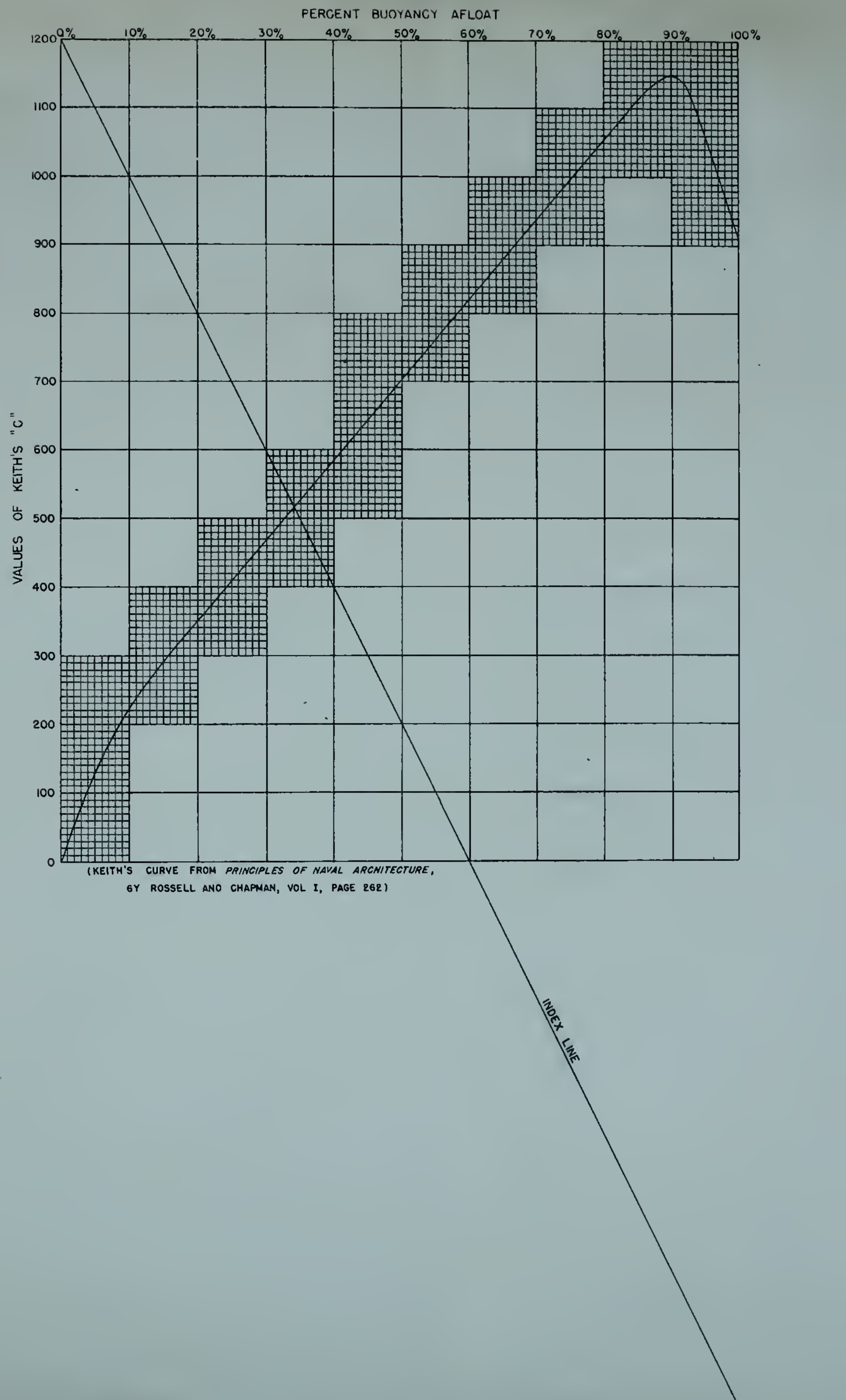
– KEY –

EXAMPLE —

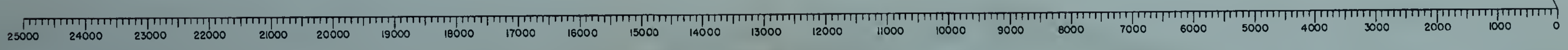
GIVEN:
"W" = 20000 TONS
"B" = 8400 TONS
REQUIRED:
TO DETERMINE "C"

1. DRAW A LINE FROM "B" = 20000 TONS TO "100 %" ON SCALE OF "PERCENT BUOYANCY AFLOAT", CROSSING INDEX LINE AT SOME POINT, X. FOR ALL VALUES OF "C" FOR A 20,000-TON SHIP, X WILL BE THE PIVOT POINT.
2. DRAW A LINE FROM "B" = 8400 TONS THROUGH X, TO "PERCENT BUOYANCY AFLOAT" SCALE.
3. PROJECT THIS POINT DOWN TO KEITH'S CURVE.
4. PROJECT THE INTERSECTION HORIZONTALLY TO THE "C" SCALE.
5. REQUIRED VALUE OF "C" = 610.

28 APRIL, 1946
R&R RHL

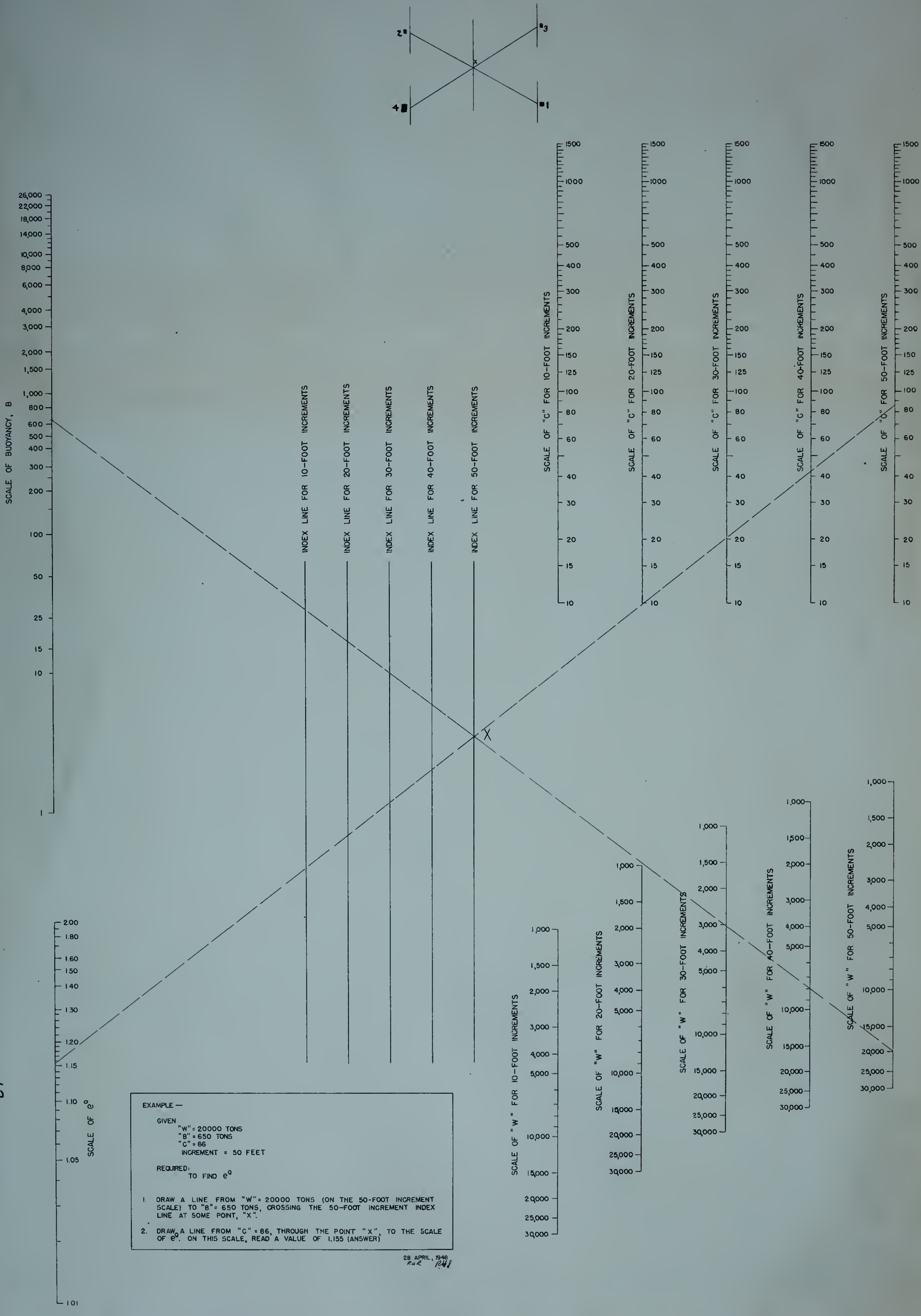


(KEITH'S CURVE FROM *PRINCIPLES OF NAVAL ARCHITECTURE*, BY ROSSELL AND CHAPMAN, VOL I, PAGE 262)



— SCALE OF "B" IN TONS —

# CHART II
## — TO DETERMINE $e^Q$ —



EXAMPLE —

GIVEN
"W" = 20000 TONS
"B" = 650 TONS
"C" = 86
INCREMENT = 50 FEET

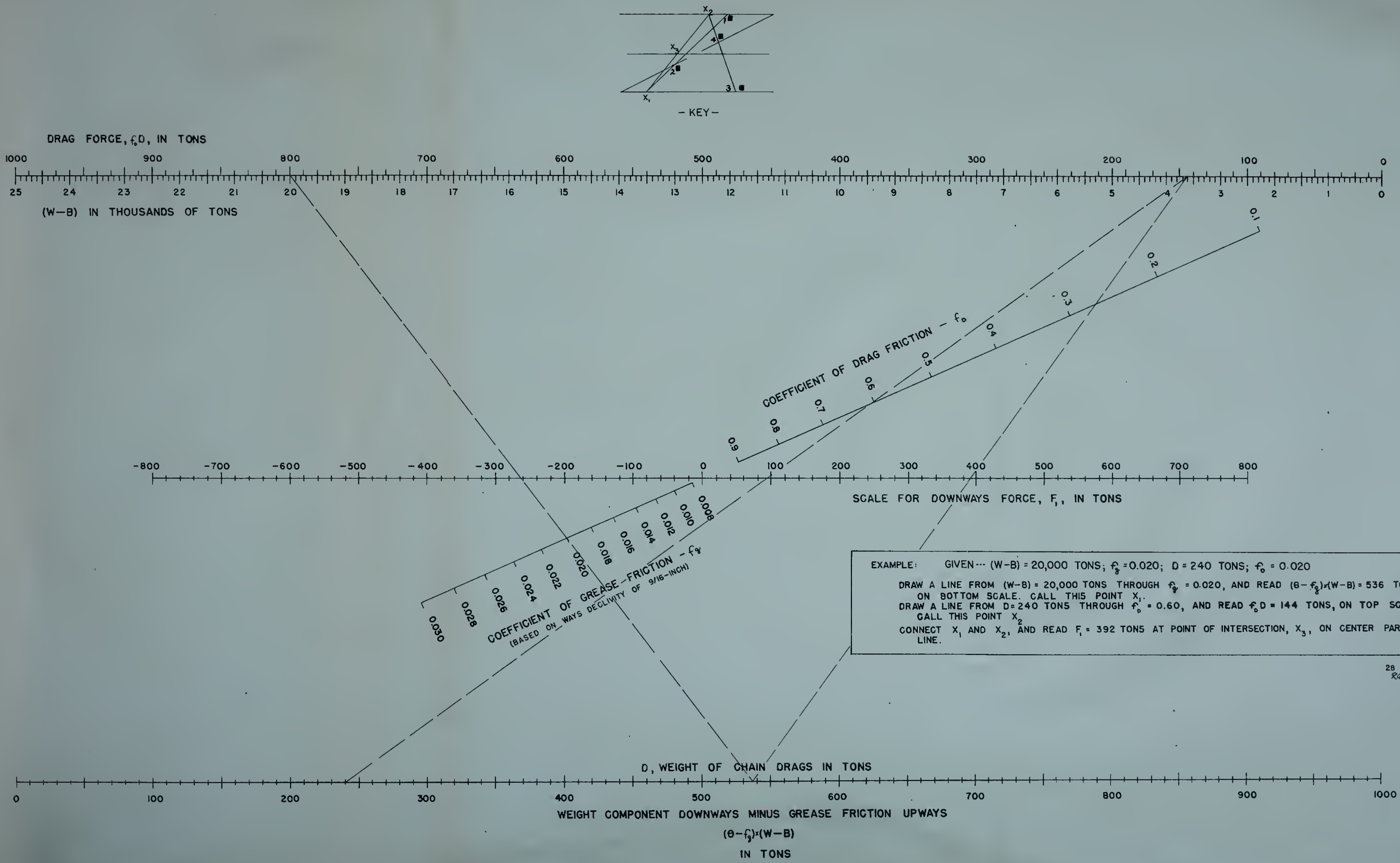
REQUIRED:
TO FIND $e^Q$

1. DRAW A LINE FROM "W" = 20000 TONS (ON THE 50-FOOT INCREMENT SCALE) TO "B" = 650 TONS, CROSSING THE 50-FOOT INCREMENT INDEX LINE AT SOME POINT, "X".
2. DRAW A LINE FROM "C" = 86, THROUGH THE POINT "X", TO THE SCALE OF $e^Q$. ON THIS SCALE, READ A VALUE OF 1.155 (ANSWER)

28 APRIL, 1948
RaR RHI

# CHART III

## — TO DETERMINE THE DOWNWAYS FORCE, $F_1$ —



EXAMPLE: GIVEN ··· (W–B) = 20,000 TONS; $f_g$ = 0.020; D = 240 TONS; $f_D$ = 0.020

DRAW A LINE FROM (W–B) = 20,000 TONS THROUGH $f_g$ = 0.020, AND READ $(\theta - f_g) \times (W-B)$ = 536 TONS ON BOTTOM SCALE. CALL THIS POINT $X_1$.

DRAW A LINE FROM D = 240 TONS THROUGH $f_D$ = 0.60, AND READ $f_D D$ = 144 TONS, ON TOP SCALE. CALL THIS POINT $X_2$

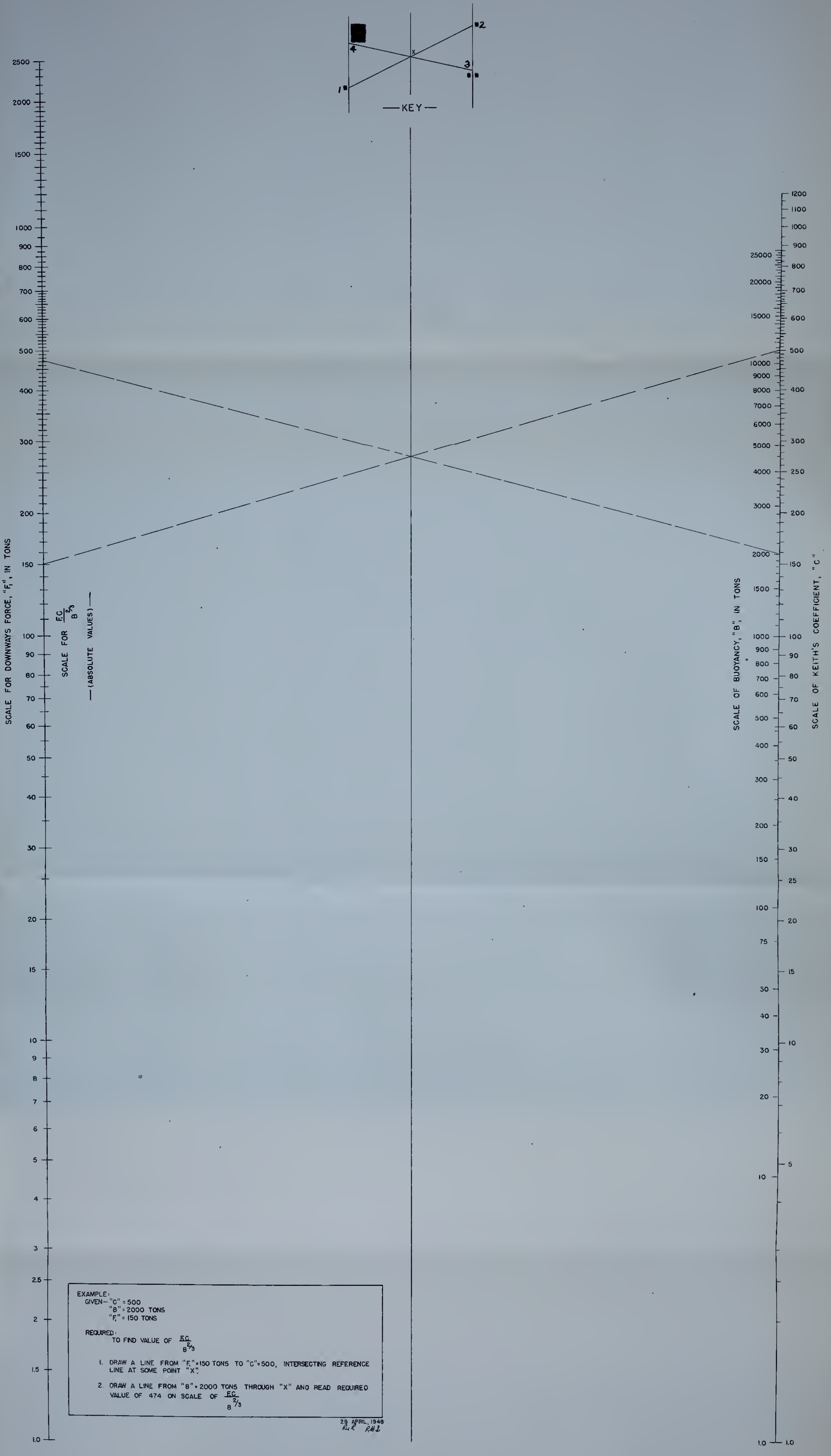
CONNECT $X_1$ AND $X_2$, AND READ $F_1$ = 392 TONS AT POINT OF INTERSECTION, $X_3$, ON CENTER PARALLEL LINE.

28 APRIL, 1948
RGR.

6732

# CHART IV

## — TO DETERMINE $\frac{FC}{B^{2/3}}$ —

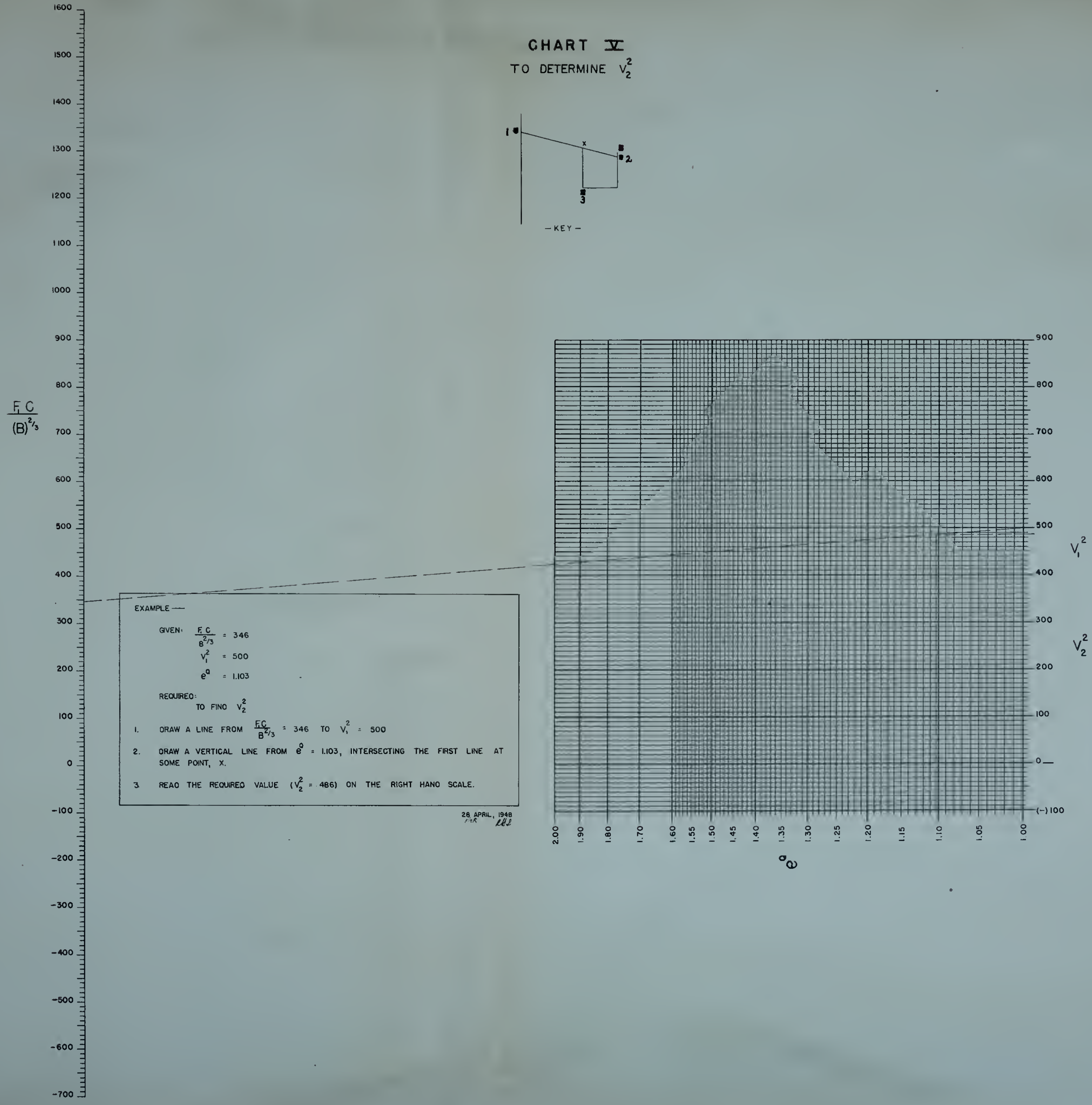


EXAMPLE:
GIVEN— "C" = 500
"B" = 2000 TONS
"$F_1$" = 150 TONS

REQUIRED:
TO FIND VALUE OF $\frac{FC}{B^{2/3}}$

1. DRAW A LINE FROM "$F_1$" = 150 TONS TO "C" = 500, INTERSECTING REFERENCE LINE AT SOME POINT "X".
2. DRAW A LINE FROM "B" = 2000 TONS THROUGH "X" AND READ REQUIRED VALUE OF 474 ON SCALE OF $\frac{FC}{B^{2/3}}$

28 APRIL, 1948
RuR RHL



# CHART V

## TO DETERMINE $V_2^2$

— KEY —

EXAMPLE —

GIVEN: $\frac{F_1C}{B^{2/3}} = 346$

$V_1^2 = 500$

$e^a = 1.103$

REQUIRED:

TO FIND $V_2^2$

1. DRAW A LINE FROM $\frac{F_1C}{B^{2/3}} = 346$ TO $V_1^2 = 500$
2. DRAW A VERTICAL LINE FROM $e^a = 1.103$, INTERSECTING THE FIRST LINE AT SOME POINT, X.
3. READ THE REQUIRED VALUE ($V_2^2 = 486$) ON THE RIGHT HAND SCALE.

28 APRIL, 1948
FAR

## DISCUSSION OF RESULTS

The following paragraphs discuss the results as found on each individual curve. A comparison of the results will be found in CONCLUSIONS AND RECOMMENDATIONS. Since variations with travel of the several variables were found to be slight, only a few points are necessary to obtain these curves.

### Curve I.

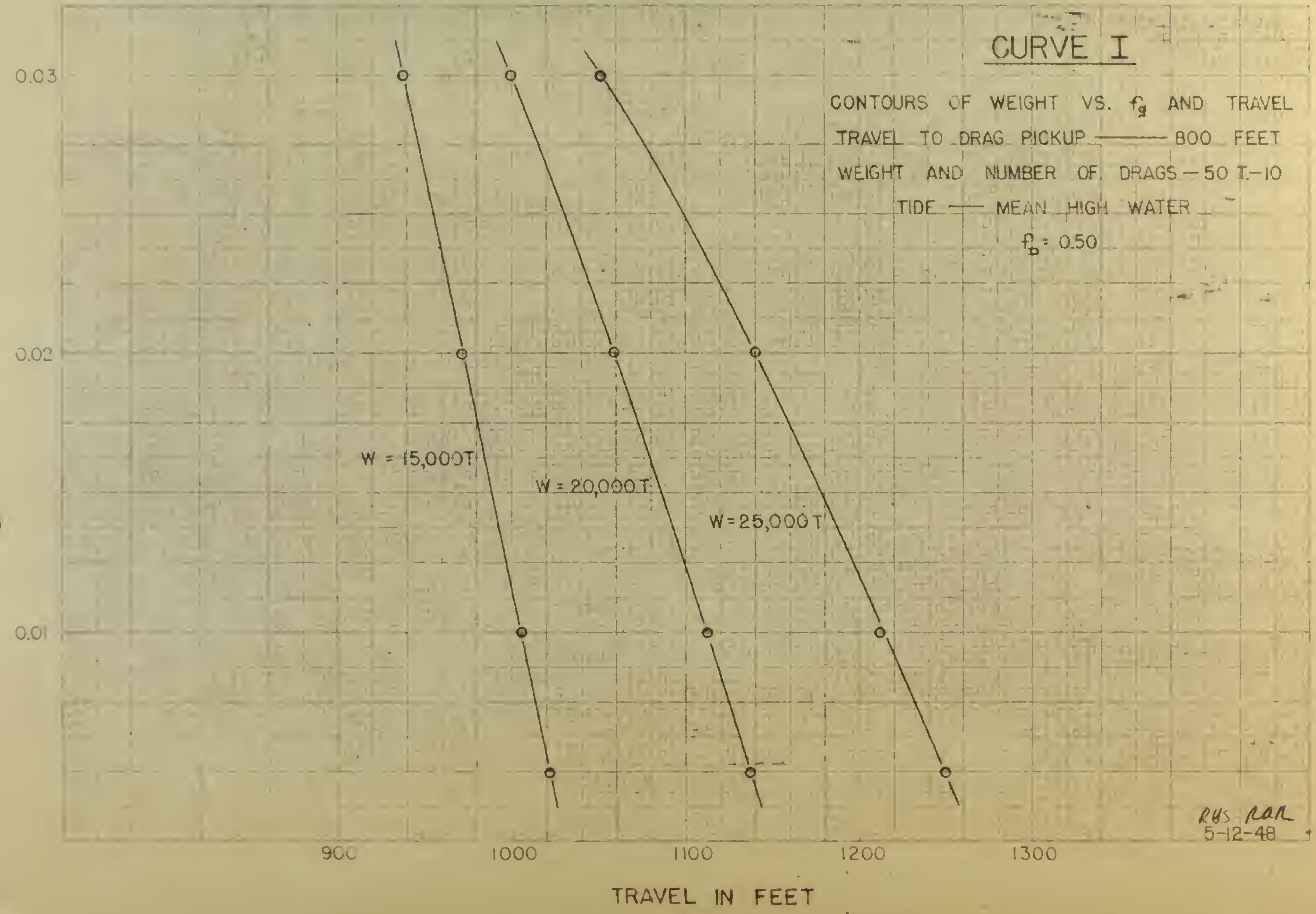
A plot of Ultimate Travel versus Coefficient of Grease Friction for Contours of Constant Weight (ship and cradle), other chart variables being held constant. The following results are noted:

1. The relative effect of the coefficient of grease friction on ultimate travel increases as the weight increases.
2. For any one weight, ultimate travel varies inversely and linearly as the coefficient of grease friction.
3. For any one coefficient of grease friction, ultimate travel is proportional to the weight.

### Curve II.

A plot of Ultimate Travel versus Coefficient of Drag Friction for Contours of Constant Weight (ship and cradle), other chart variables being held constant. The following results are noted:

1. The relative effect of the coefficient of drag friction on the ultimate travel increases as the displacement increases.



## CURVE I

CONTOURS OF WEIGHT VS. $f_g$ AND TRAVEL

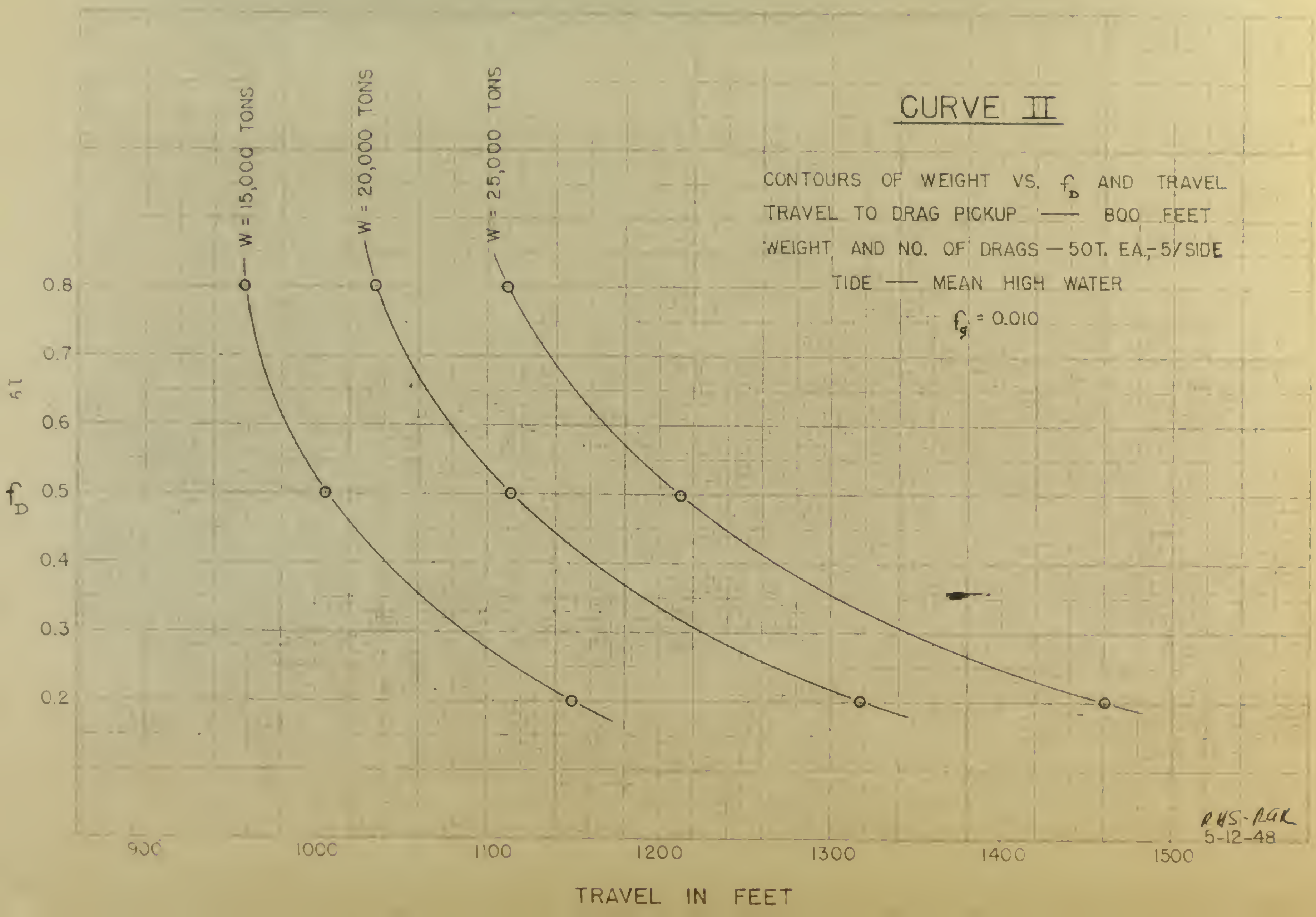
TRAVEL TO DRAG PICKUP —— 800 FEET

WEIGHT AND NUMBER OF DRAGS — 50 T.—10

TIDE —— MEAN HIGH WATER

$f_D = 0.50$

RHS RAR
5-12-48



# CURVE II

CONTOURS OF WEIGHT VS. $f_D$ AND TRAVEL

TRAVEL TO DRAG PICKUP —— 800 FEET

WEIGHT AND NO. OF DRAGS — 50T. EA.,- 5/SIDE

TIDE —— MEAN HIGH WATER

$f_g = 0.010$

RHS-RGK
5-12-48

2. For any one weight, ultimate travel does not vary inversely as the coefficient of drag friction in a straight line manner; instead it is concave to the right. This is to be expected, since with zero coefficient of drag friction the travel is theoretically infinite.

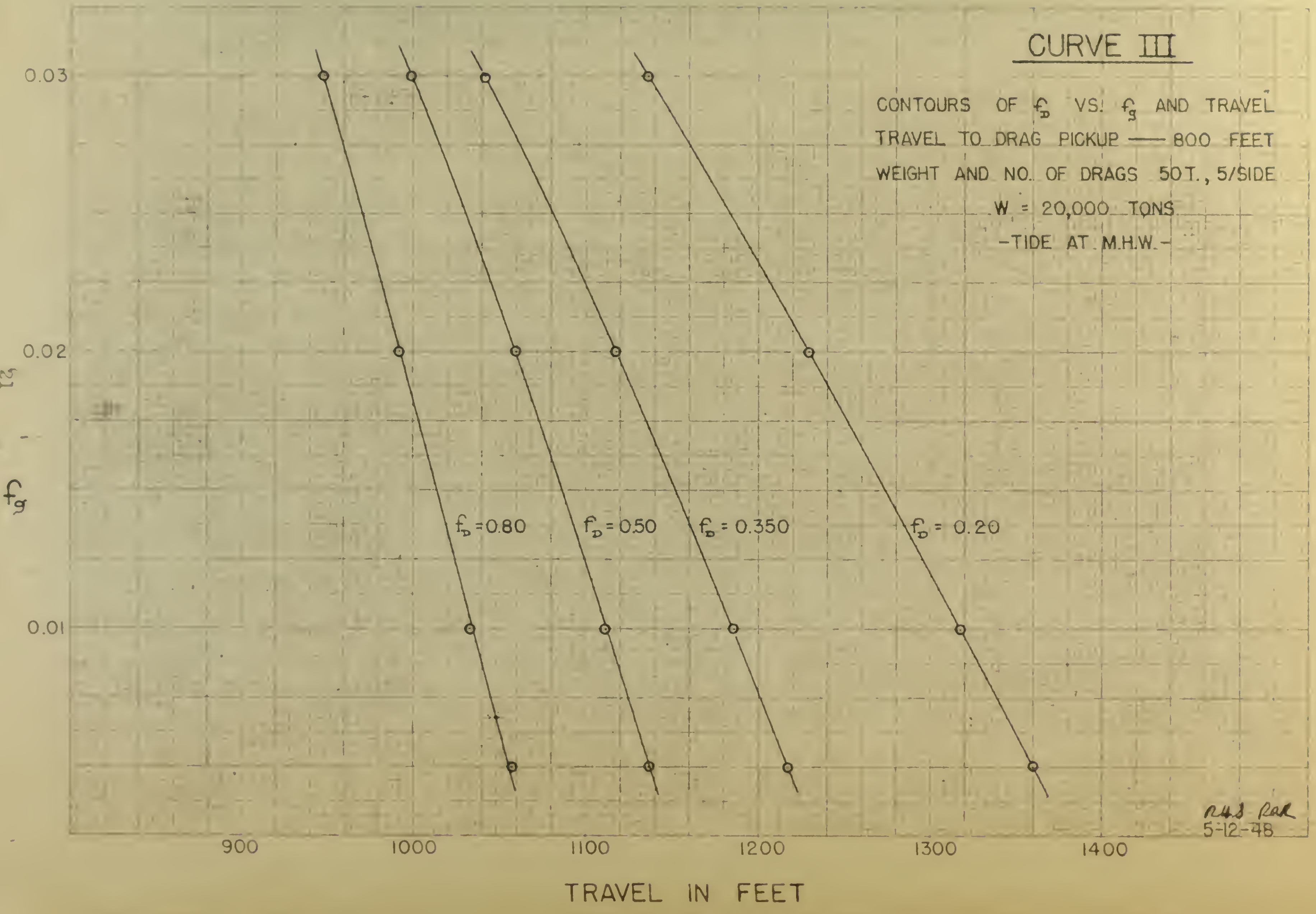
Curve III.

A plot of Ultimate Travel versus Coefficient of Grease Friction for Contours of Constant Drag Friction Coefficient, other chart variables being held constant. The following results are noted:

1. The relative effect of the coefficient of grease friction upon ultimate travel decreases as the coefficient of drag friction increases.
2. For any one coefficient of drag friction, ultimate travel varies inversely and linearly as the coefficient of grease friction.
3. For any one coefficient of grease friction, ultimate travel increases exponentially with a decrease in coefficient of drag friction. For the vessel analyzed by this curve the following relationship was found:-

$$\text{Ultimate travel} \propto f_D^{-1/5}$$

4. The construction of this type of plot which uses extreme expected values of coefficient of grease friction and coefficient of drag friction (other chart variables being



## CURVE III

CONTOURS OF $f_D$ VS. $f_g$ AND TRAVEL

TRAVEL TO DRAG PICKUP —— 800 FEET

WEIGHT AND NO. OF DRAGS 50T., 5/SIDE

W = 20,000 TONS

-TIDE AT M.H.W.-

held constant) is very useful since it shows the combination of coefficients for minimum expected travel, maximum expected travel, and all in-between values.

Curve IV.

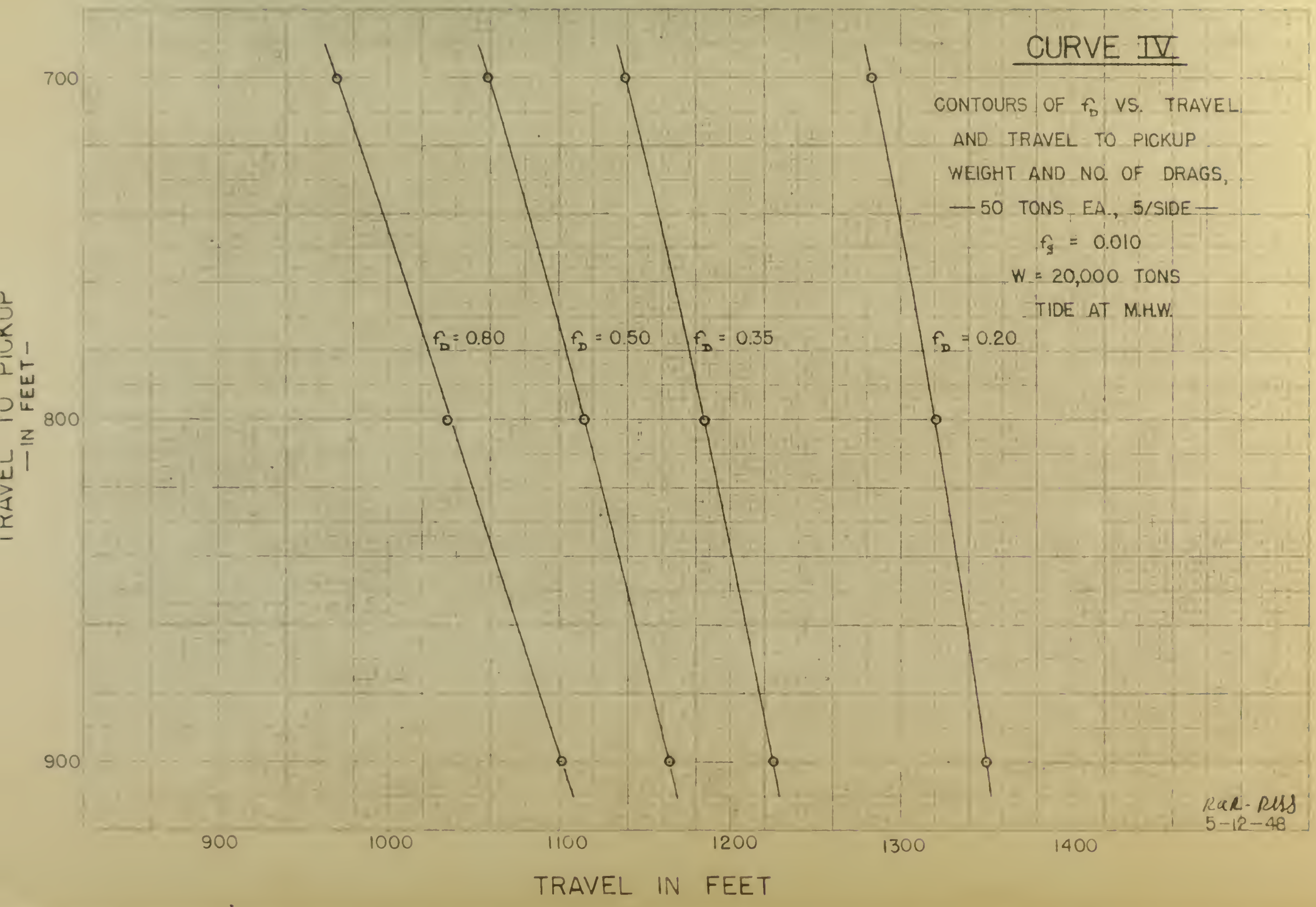
A plot of Point of Pickup of Chain Drags versus Ultimate Travel for Contours of Constant Coefficient of Drag Friction, other chart variables being held constant. The following results are noted:

1. The relative effect of a change in the point of pickup upon ultimate travel increases as the coefficient of drag friction increases.
2. For any one coefficient of drag friction, ultimate travel varies linearly with a change in the point of pickup.
3. The increase of ultimate travel is less than the extension of travel to the point of pickup. In one case, where the point of pickup is delayed 60 feet, the ultimate travel of the vessel is only 40 feet greater.

Curve V.

A plot of Height of Tide versus Ultimate Travel of Vessel, all other chart variables being held constant. The following result is noted:

1. The effect of a variation in the height of tide upon ultimate travel is practically negligible. For a tide variation of approximately 3 feet, the variation of



## CURVE IV

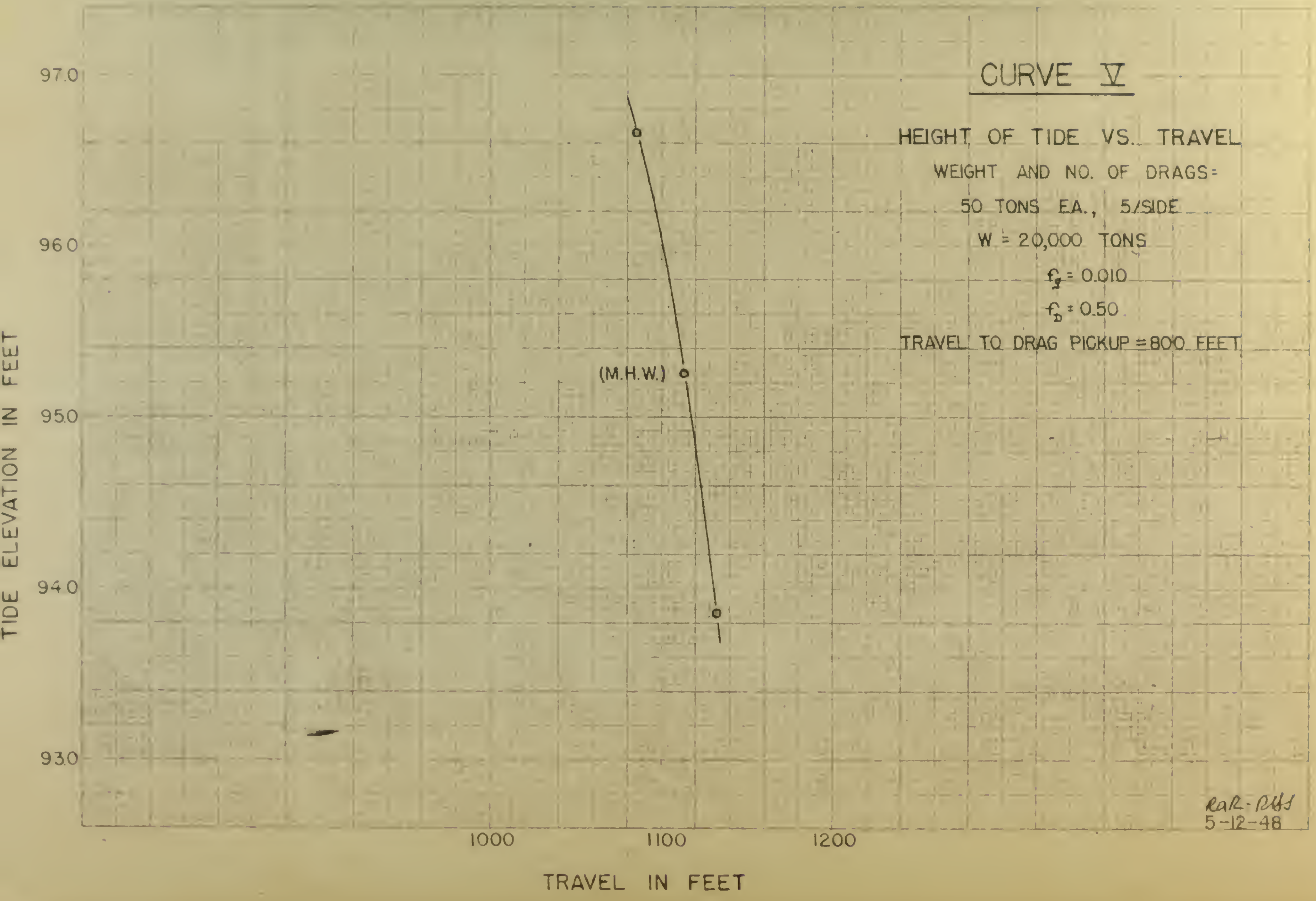
CONTOURS OF $f_D$ VS. TRAVEL AND TRAVEL TO PICKUP WEIGHT AND NO. OF DRAGS, —50 TONS EA., 5/SIDE—

$f_g = 0.010$

W = 20,000 TONS

TIDE AT M.H.W.

RAR-RUS
5-12-48



## CURVE V

HEIGHT OF TIDE VS. TRAVEL

WEIGHT AND NO. OF DRAGS:
50 TONS EA., 5/SIDE
W = 20,000 TONS
$f_s = 0.010$
$f_D = 0.50$
TRAVEL TO DRAG PICKUP = 800 FEET

RaR-RHS
5-12-48

ultimate travel was only 50 feet. It must be realized, however, that the height of tide is a very important factor in determining the way-end pressure produced at launching.

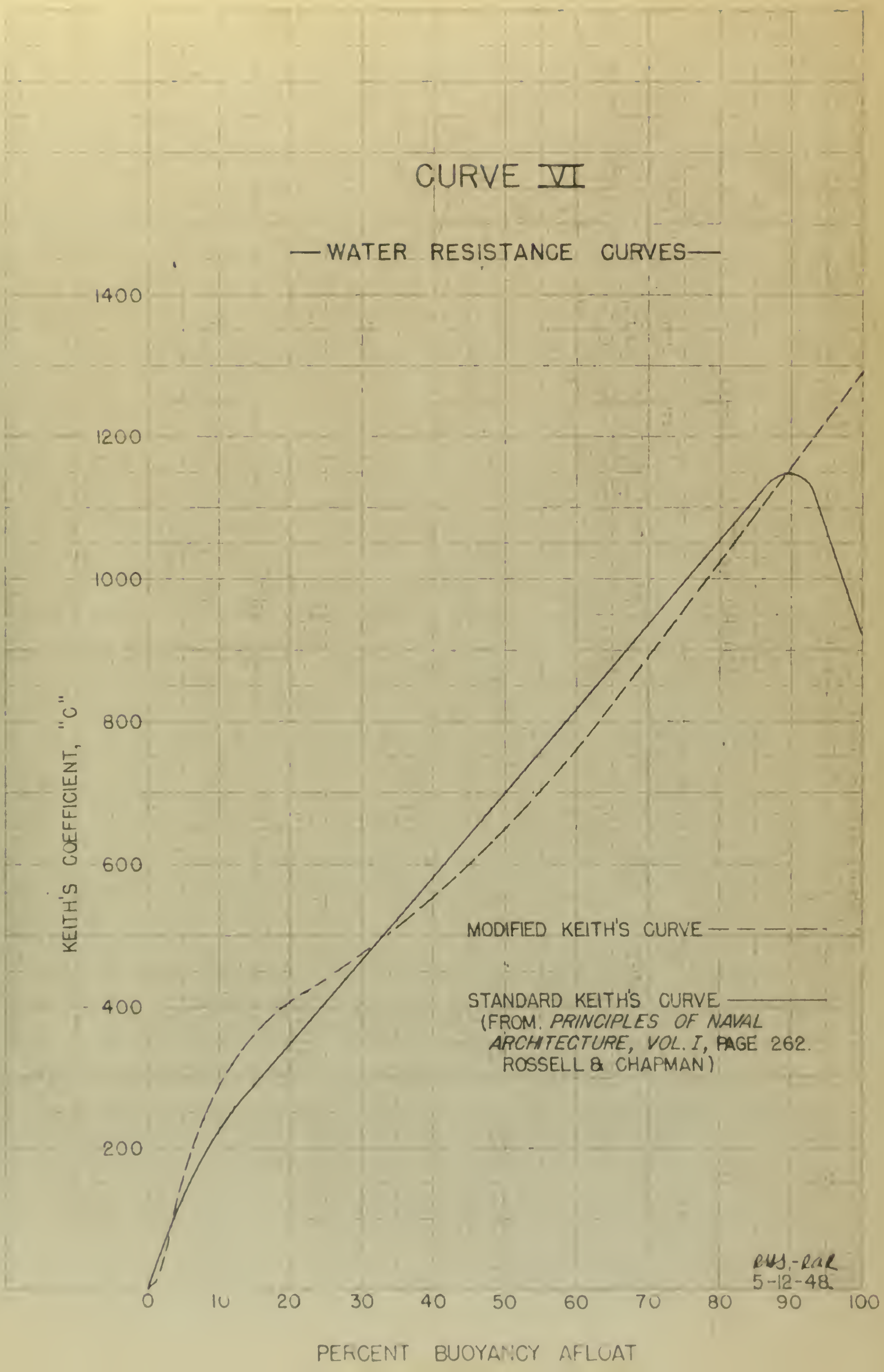
Curve VI.

A plot of the curve of Standard Keith's Coefficient, "C", of Water Resistance versus a Modified Curve of Keith's Coefficient, "C", the area under each curve being kept constant. The authors have assumed that the standard Keith's Curve was constructed from data obtained on ship launchings at which large chain drag forces were present.

In calculating the ultimate travel for a ship utilizing large chain drag forces, (using first the Standard Keith's Curve and then the Modified Keith's Curve, holding all other variables constant), it was found that the use of the Modified Keith's Curve increased the ultimate travel by only some 20 feet. Thus, the "100% Buoyancy Afloat" value of Keith's Coefficient, "C", has relatively little effect upon the calculated point of ultimate travel when large chain drag forces are applied. However, if the drag force is considerably reduced, the vessel will travel a greater distance in a fully waterborne condition and the end value of Keith's Coefficient becomes extremely important inasmuch as it determines almost the total resistance during this interval.

# CURVE VI

## —WATER RESISTANCE CURVES—



RHS.-RAL
5-12-48

## CONCLUSIONS AND RECOMMENDATIONS

The form of the basic equation ( 2 ), is that of a recursion formula. That is, to find the ultimate travel, or point at which $V_f^2 = 0$, one cannot simply substitute values into a formula and solve for $V_f^2$. This is because the several variables come into play at different times during travel, or in other words, the functions of the variables are discontinuous. The step-by-step method lends itself to determination of $V_f^2$ for increments of travel over which these functions are continuous, thus giving a curve of velocities which, when plotted against travel, is a close approximation to the actual velocity curve. With these circumstances in mind, the nomograms developed in this thesis report greatly reduce the steps required to find the points on the velocity curve. For the same reason that no one formula will yield the ultimate travel, no one nomogram will.

From a comparison of Curves I through VI, the following conclusions are drawn:

1. The net chain drag force is the most important variable affecting the ultimate travel of a vessel at launching.
2. The resultant increase in ultimate travel caused by a delay in the point of pickup of chain drags is less than the delay in point of pickup.
3. A moderate variation in the height of tide has very little

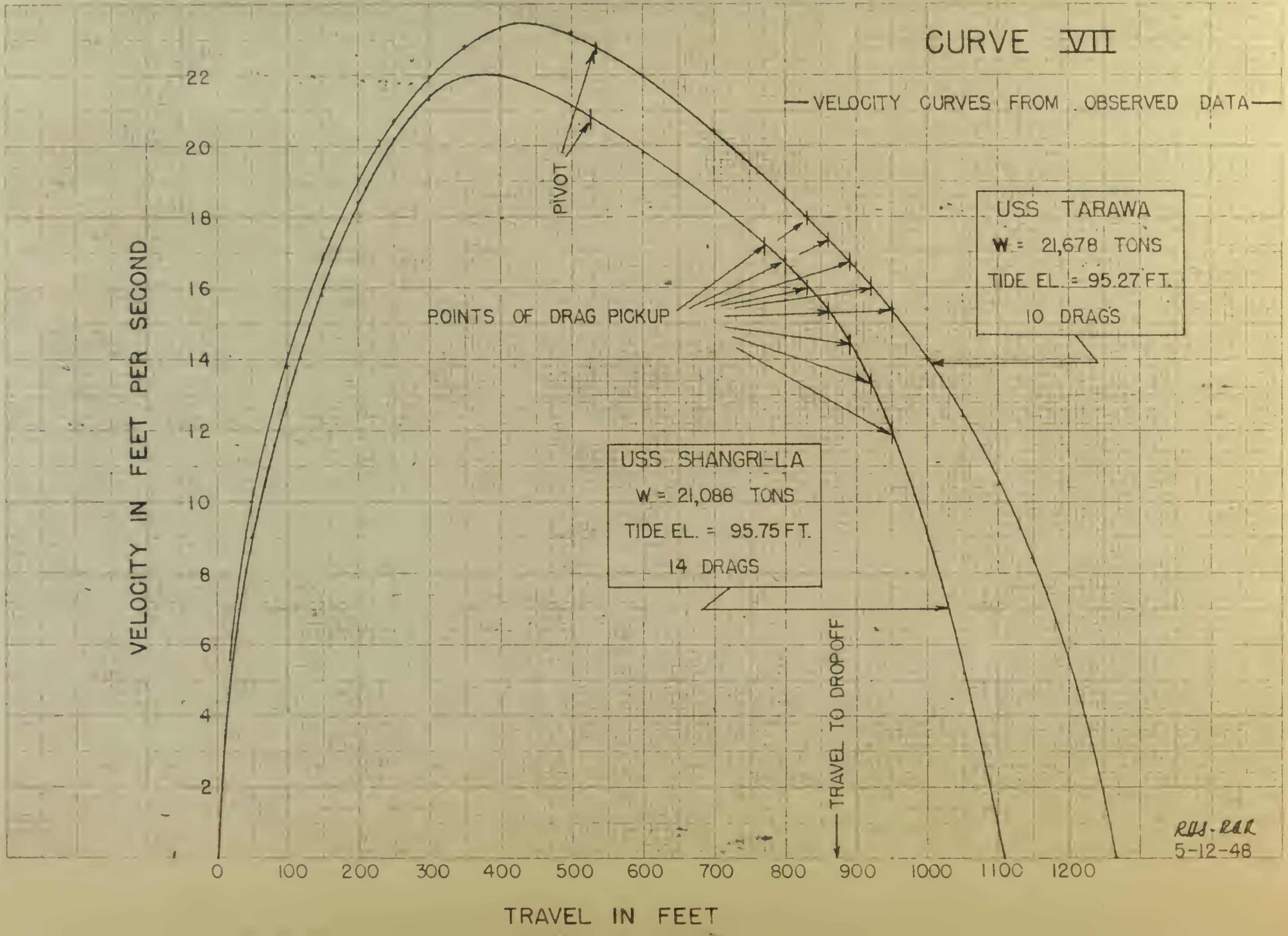
effect upon ultimate travel of a vessel at launching.

4. A variation in the coefficient of grease friction has little effect upon the ultimate travel of a vessel at launching. Thus, the atmospheric temperature on the day of launching, which affects the coefficient of grease friction, need not be an important consideration.
5. A moderate change in the combined weight of the vessel and its cradle has little effect upon ultimate travel.
6. The value of Keith's Coefficient, "C", of Water Resistance when the vessel is completely waterborne becomes increasingly important in determining the point of ultimate travel as the interval of completely waterborne travel increases.

The nomographic charts developed herein present a rapid means of obtaining the point of ultimate travel at launching when use is made of the force equation outlined in the PROCEDURE. These charts will yield an answer in about one-fourth of the time required by the conventional methods of step-by-step calculations with far less likelihood of error, since less computation is required. It must be understood that the accuracy of the end point result obtained is no greater than that of the assumed coefficients. Also, these nomographic charts furnish a more accurate means of calculating than an ordinary ten-inch slide rule.

All numerical results contained in this thesis are based on calculations using the Standard Curve of Keith's Coefficient, "C", of Water Resistance as found on Chart I. In the event that a modified form of Keith's Curve is to be used it may be substituted for the Standard Keith's Curve on Chart I and the same nomographic method applied to obtain the desired point of ultimate travel.

A further investigation seems warranted to determine the accuracy of the end point value (fully waterborne condition) of Keith's Coefficient, "C", of Water Resistance. From recent launching data (USS SHANGRI-LA, CV-38), the end point value of "C" appears to be about 1400. This was computed from data obtained with a gyro-accelerometer mounted on board the vessel at the time of launching. The velocity curve derived from this accelerometer is shown in Curve VII.


CURVE VII
—VELOCITY CURVES FROM OBSERVED DATA—
USS TARAWA
W = 21,678 TONS
TIDE EL. = 95.27 FT.
10 DRAGS
USS SHANGRI-LA
W = 21,088 TONS
TIDE EL. = 95.75 FT.
14 DRAGS
PIVOT
POINTS OF DRAG PICKUP
TRAVEL TO DROPOFF
VELOCITY IN FEET PER SECOND
22
20
18
16
14
12
10
8
6
4
2
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
TRAVEL IN FEET
RDS-RAR
5-12-48

# APPENDIX

## General Equations

To determine the velocity of a vessel at any point of its travel, a step-by-step method of calculation must be used. The step taken is from a known velocity to the point of travel where the desired velocity obtains. A maximum of fifty feet per step or increment of travel, is used in this thesis.

At least two types of equations for the determination of the ultimate travel of a ship upon launching are used in present day practice, the force equation and the energy equation.

This thesis considers only the force equation, which states that the resultant force acting on the ship in its line of motion equals the mass of ship and cradle times its acceleration.

The following symbols are used:

$W$ = Weight of ship and cradle, in tons

$B$ = Average buoyancy of ship, in tons, over increment of travel, read from Chart VIII, (Cradle is assumed self buoyant)

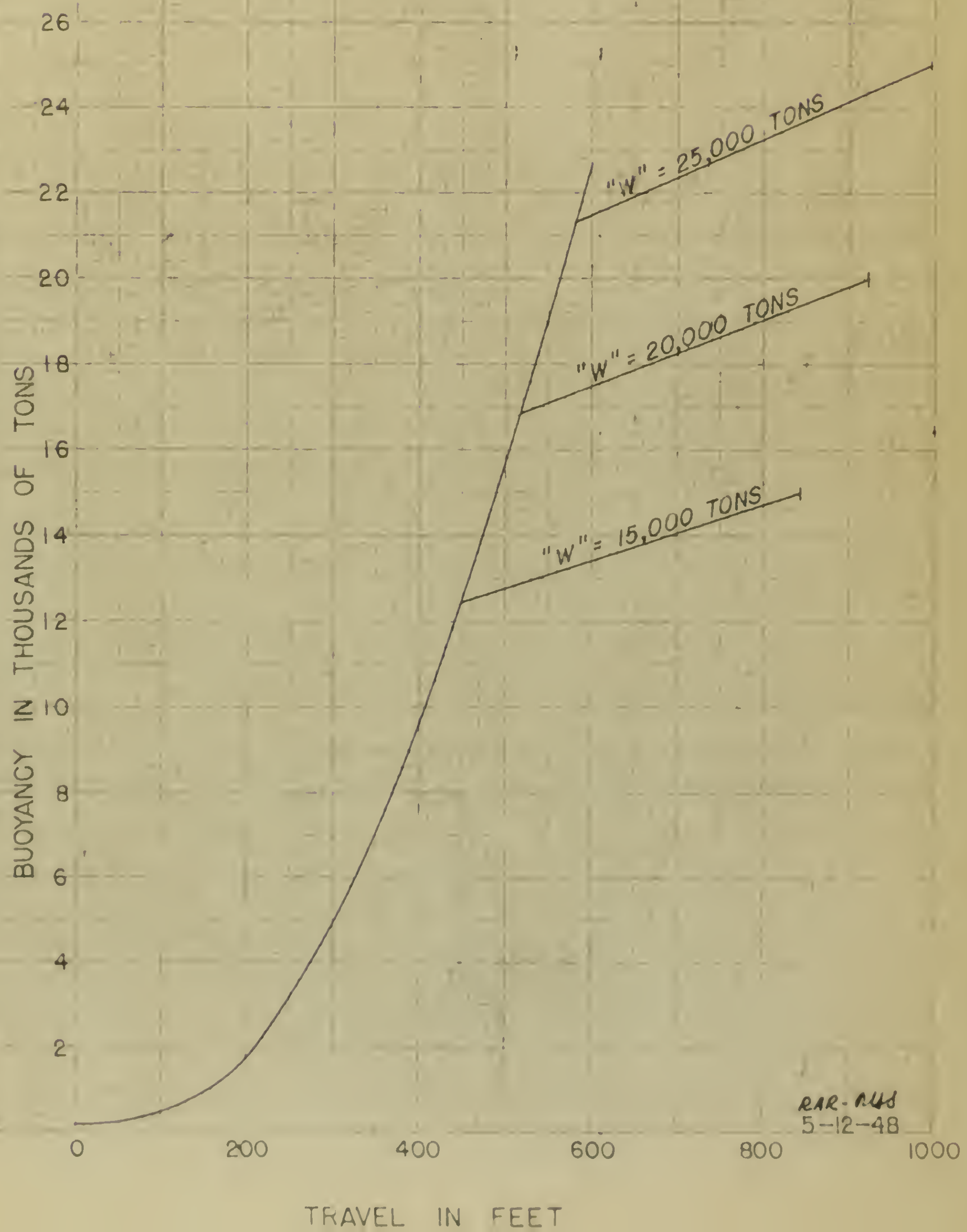
$\theta$ = Angle of declivity of ways

$a$ = Acceleration of ship in line of travel

$F_1$ = Average downways component of ship's weight minus the average upways components of:

## CURVE VIII

— BUOYANCY CURVES —



1. Buoyancy
2. Grease friction
3. Chain drag resistance

$g$ = Gravitational constant

$S_1$ = Distance ship travels to beginning of any increment

$S_2$ = Distance ship travels to end of any increment

$S'$ = Distance ship travels beyond last increment for $V_2^2$ positive

$S$ = $S_2 - S_1$

$V_1$ = Velocity at point of travel, $S_1$

$V_2$ = Velocity at point of travel, $S_2$

$V_f$ = Velocity at end of any increment in general

$D$ = Weight of chain drags in action

$f_g$ = Coefficient of grease friction

$f_d$ = Coefficient of chain drag friction (or resistance)

$K$ = Constant of proportionality between water resistance in tons and ship's speed, $V^2$, in (ft./sec.)$^2$

$= \dfrac{B^{2/3}}{C}$

$C$ = Keith's Coefficient of water resistance

The derivation of the equation for velocity at the end of any increment of travel follows:

From fundamental mechanics

$$F_{NET} = \text{MASS} \times \text{ACCELERATION}$$

$$F_{NET} = \frac{W a}{g}$$

$$\frac{g F_{NET}}{W} = a = \frac{dv}{dt} = \frac{dv}{ds} \cdot \frac{ds}{dt} = V \frac{dv}{ds}$$

So, $$\frac{g F_{NET}}{W} = V \frac{dV}{ds} \qquad (5)$$

Let us assume that the drag force and grease friction act in the direction of the line of motion of the vessel. Then the total force causing acceleration is:

$$F_1 - KV^2 = F_{NET} \qquad (6)$$

where $KV^2$ is the resistance of the water and K is determined from Keith's Curve of Water Resistance Coefficients.

Therefore, $$\frac{g}{W}(F_1 - KV^2) = V \frac{dv}{ds} \qquad (7)$$

Note that average values of $F_1$ and K over the increment are to be used, so that the forces may be considered as constants for the entire increment in question.

Separating the variables in Equation (7), we obtain:

$$\frac{g\,ds}{W} = \frac{V\,dV}{F_1 - KV^2} \tag{8}$$

and integrating both sides between limits;

$$\frac{g}{W}\int_{S_1}^{S_2} ds = \frac{1}{-2K}\int_{V_1}^{V_2} \frac{(-2K)V\,dV}{F_1 - KV^2} \tag{9}$$

$$\frac{-2gK}{W}\left(S_2 - S_1\right) = \Big[\log_e \left(F_1 - KV^2\right)\Big]_{V_1}^{V_2} \tag{10}$$

$$\frac{-2gK}{W}\left(S_2 - S_1\right) = \log_e \left\{\frac{F_1 - KV_2^2}{F_1 - KV_1^2}\right\} \tag{11}$$

Taking antilog of both sides of Equation (11),

$$e^{\frac{-2gK}{W}(S_2 - S_1)} = \frac{F_1 - KV_2^2}{F_1 - KV_1^2} \tag{12}$$

$$\left(F_1 - KV_1^2\right) e^{\frac{-2gK}{W}(S_2 - S_1)} = F_1 - KV_2^2 \tag{13}$$

$$\frac{F_1}{K} - \frac{\left(F_1 - KV_1^2\right)}{K}\, e^{\frac{-2gK}{W}(S_2 - S_1)} = V_2^2 \tag{14}$$

Equation (14), after putting $K = \frac{B^{2/3}}{C}$, reduces to:

$$V_2^2 = \frac{1}{e^{\frac{2gK}{W}(S_2-S_1)}}\left[V_1^2 + \frac{CF_1\left(e^{\frac{2gK}{W}(S_2-S_1)}-1\right)}{B^{2/3}}\right] \qquad (15)$$

Where $F_1 = (W-B)\sin\theta - (W-B)f_g\cos\theta - Df_d$

The foregoing expression is further simplified by saying that, since $\theta$ is quite small,

$\sin\theta = \theta$, in radians

$\cos\theta = 1.00$

Therefore, $F_1 = (W-B)(\theta - f_g) - Df_d \qquad (16)$

One of the objectives of this thesis is to develop a rapid method of finding the end point of travel (at which $V_2^2 = 0$), based on assumed values of retarding variables. The method developed is discussed in the next section.

## Development of Nomographic Charts.

CHART I is a Z-type nomogram used to determine the percent buoyancy afloat. Keith's curve is drawn as given in Principles of Naval Architecture, Vol. I., Page 262, with the Z-type chart below it. "B" is read from Curve VIII and averaged over the increment. In Fig. (1), it can be seen by similar triangle analysis,

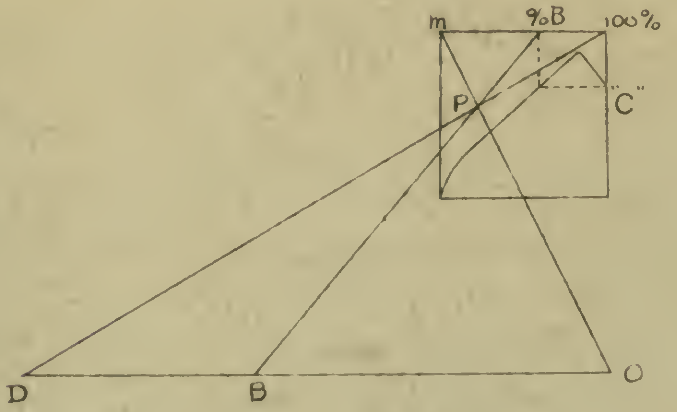


Figure I

Since $$\frac{\overline{OB}}{\%B} = \frac{\overline{OP}}{\overline{mP}} \qquad (17)$$

and $$\frac{\overline{OD}}{100\%(B)} = \frac{\overline{OD}}{1} = \frac{\overline{OP}}{\overline{mP}} \qquad (18)$$

therefore $$\%B = \frac{\overline{OB}}{\overline{OD}} \qquad (19)$$

Therefore, the value of "%B Afloat" is correct as read. "C" is read as from a normal graph by noting the intersection of the absissca of "%B Afloat" and the "C" curve.

CHART II is a nomogram to determine values of $e^Q$, based on equation:

$$e^Q = e^{\frac{2B^{2/3}gS}{WC}} \qquad (S = S_2 - S_1) \qquad (20)$$

Taking $\log_{10}$ of both sides, twice,

$$\log_{10} e^Q = \frac{2B^{2/3}gS}{WC}\cdot\log_{10}e \qquad (21)$$

$$\log_{10}\log_{10} e^Q = \frac{2}{3}\log_{10}B + \log_{10}2g + \log_{10}S - \log_{10}W - \log_{10}C + \log_{10}\log_{10}e \qquad (22)$$

$$\frac{2}{3}\log_{10}B - \log_{10}\log_{10}e^Q = \log_{10}W + \log_{10}C - \log_{10}(2gS\log_{10}e) \qquad (23)$$

This gives the form of Chart II, which can be proved by congruent triangles if the index line is midway between the scales for "C" and "B".

To simplify the chart design, lay off values of $\frac{2}{3}\log_{10}B$ as a B scale, and values of $\log_{10}\log_{10} e^{Q}$ as an $e^{Q}$ scale on the same line. Draw a "C" scale as on Chart II, using values of $\log_{10}C$ with the index line midway between the "C"- and "B"-scales, as shown. Then, calculate $e^{Q}$ for any reasonable values of "W", "C", and "B". If a value of "W" = 1000 is used, the process of laying out the "W"-scale is simplified. Draw a line between the points of "C" and $e^{Q}$, crossing the index line at some point X. A line from the chosen value of "B" through X determines "W" on a line of the "C"-scale extended. From this point, and to the same scale as "C", lay off values of $\log_{10}W$ using standard $\log_{10}$ tables. A second similar calculation with the assumed value of "W" greater than the first will determine the direction of the "W"-scale.

Note that "B" is always less than or equal to "W" for any given ship.

CHART III is a nomogram to determine the downways force, $F_1$, and is a pair of Z-charts with a difference scale superimposed.

It is desired to solve the following equation:

$$F_1 = (W-B)\theta - f_g(W-B) - f_dD \qquad (24)$$

$$F_1 = (\theta - f_g)(W-B) - f_dD \qquad (25)$$

The Z chart is constructed as follows:

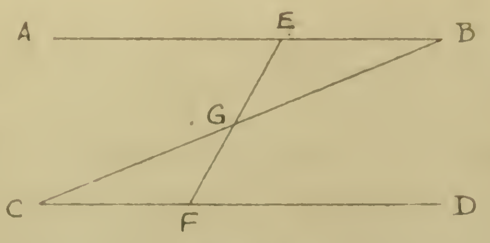


Figure II

Draw two parallel lines $\overline{AB}$ and $\overline{CD}$, and draw $\overline{BC}$. Connect E and F from any points on $\overline{AB}$ and $\overline{CD}$, intersecting $\overline{BC}$ in some point G.

Since triangles EBG and CGF are similar, $\overline{EB}$ = const x $\overline{CF}$. This is the form desired to solve Equation (25).

To lay out the chart for the first term of the right hand side of Equation (25), mark divisions to some convenient scale of (W-B) on $\overline{BA}$. To any convenient scale on $\overline{CD}$, lay out values for $(\theta - f_g)$(W-B). Then, with any convenient values of $(\theta - f_g)$ and (W-B), calculate the product $(\theta - f_g)$(W-B). Mark this point on its scale. Draw $\overline{EF}$, labeling the point G, (on the line connecting the zero points of the (W-B)- and $(\theta - f_g)$(W-B)-scales), with the value of $f_g$ used in the calculation. Point G will thus be the pivot point for all values of (W-B) and the assumed value of $f_g$ with a slope of ways equal to $\theta$. Pivot points for other

values of $f_g$ are calculated similarly.

CHART III is designed for slope of 9-16", but pivot points on the $f_g$ scale for other declivities can be readily located by the method just described. Scales similar to those for (W-B), $f_g$, and $(\theta - f_g)(W-B)$ are laid off on CD, CB, and BA for weight of drags, D, drag coefficient of resistance, $f_d$, and drag force $Df_d$.

Midway between $\overline{AB}$ and $\overline{CD}$, a parallel line is drawn on which is drawn a scale of differences between the scales of $(\theta - f_g)(W-B)$ and $Df_d$. Each of these points is located by taking any convenient values of $(\theta - f_g)(W-B)$ and $Df_d$, subtracting them, drawing a line between them cutting the difference scale line at a point, and labeling the point with the computed difference. Thus, the scale of the difference line is at once determined.

CHART IV is a nomogram used to determine $\frac{F_1C}{B^{2/3}}$. Taking the $\log_{10}$ of this, we have:

$$\log_{10}\frac{F_1C}{B^{2/3}} = \log_{10}F_1 + \log_{10}C - \frac{2}{3}\log_{10}B \qquad (26)$$

$$\log_{10}F_1 - \log_{10}\frac{F_1C}{B^{2/3}} = \frac{2}{3}\log_{10}B - \log_{10}C \qquad (27)$$

To construct the chart, draw three parallel equidistant lines $\overline{AB}$, $\overline{CD}$, $\overline{EF}$.

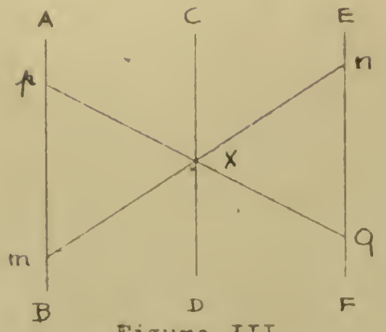


Figure III

Draw $\overline{mn}$ and $\overline{pq}$, causing them to intersect at some point X, on $\overline{CD}$. From any reference point below m and q, lay off a $\log_{10}$ scale on $\overline{BA}$ and on $\overline{FE}$. Because of the congruent triangles pXm and nXq, pm = nq. If n is laid off as $\frac{2}{3}\log_{10} B$, q as $\log_{10} C$, p as $\log_{10} F_1$, then m will lie on the value of $\frac{F_1 C}{B^{2/3}}$. Due to ambiguities of sign and construction, Chart IV must be used in the following order:

1. Draw a line from $F_1$ to C.
2. Draw a line from B through X to locate $\frac{F_1 C}{B^{2/3}}$.

Note, the algebraic sign of $\frac{F_1 C}{B^{2/3}}$ is the same as that of $F_1$.

CHART V is a nomogram to determine $V_2^2$ and is designed in a different manner from the others. This chart is used to solve the final equation whose component parts are determined by Charts I through IV.

The equation is:

$$V_2^{\,2}\, e^Q - V_1^{\,2} = M(e^Q - 1) \qquad (28)$$

Where $M = \frac{F_1 C}{B^{2/3}}$

Let $x = V_2^{\,2}$

$y = M$

Writing parametric equations, we have:

$$\begin{aligned} e^Q x - y(e^Q - 1) &= V_1^{\,2} \\ x &= V_2^{\,2} \qquad (29) \\ y &= M \end{aligned}$$

The determinant of this may be written:

$$\begin{vmatrix} e^Q & -(e^Q-1) & V_1^{\,2} \\ 1 & 0 & V_2^{\,2} \\ 0 & 1 & M \end{vmatrix} = \begin{vmatrix} e^Q & 1 & V_1^{\,2} \\ 1 & 1 & V_2^{\,2} \\ 0 & 1 & M \end{vmatrix} = \begin{vmatrix} 1 & V_1^{\,2} & 1 \\ \frac{1}{e^Q} & V_2^{\,2} & 1 \\ 0 & M & 1 \end{vmatrix} = 0 \qquad (30)$$

But this is the equation of a straight line laid out on x-y axes. When $x = 1$, $y = V_1^{\,2}$; when $x = \frac{1}{e^Q}$, $y = V_2^{\,2}$; when $x = 0$, $y = M$. A perusal of Chart V will disclose the method of plotting.

The scale of $\frac{F_1C}{B^{2/3}}$ is the y-axis, and although the scale of $\frac{1}{e^{Q}}$ is plotted on the x-axis; the label for each point is "$e^{Q}$".

Typical examples are shown in Tables I and II. Table I is computed with aid of the charts, while Table II is computed with sliderule and calculating machine. The former table required one hour to fill in; the latter, about four hours. The chance of error in using Table I with the charts is negligibly small compared to the calculating machine method. The difference in the answers obtained by the two methods is quite negligible, being only four feet in 1100 feet for the example as shown in Tables I and II.

# TABLE I

## Nomographic Chart Method

## For Determination of Ultimate Travel

| Travel | S | B (Avg.) | C | $e^Q$ | W-B | $F_1$ | $\frac{F_1C}{B^{2/3}}$ | $V_2^2$ | $V_2$ |
|---|---|---|---|---|---|---|---|---|---|
| 0-50 | 50 | 200 | 28 | 1.22 | 19,800 | 730 | 598 | 108 | 10.4 |
| 50-100 | 50 | 325 | 47 | 1.18 | 19,675 | 726 | 722 | 201 | 14.2 |
| 100-150 | 50 | 650 | 86 | 1.15 | 19,350 | 714 | 820 | 281 | 16.8 |
| 150-200 | 50 | 1300 | 160 | 1.128 | 18,700 | 690 | 920 | 352 | 18.8 |
| 200-250 | 50 | 2500 | 260 | 1.123 | 17,500 | 646 | 910 | 415 | 20.4 |
| 250-300 | 50 | 4100 | 355 | 1.121 | 15,900 | 587 | 805 | 458 | 21.4 |
| 300-350 | 50 | 6100 | 475 | 1.120 | 13,900 | 514 | 730 | 486 | 22.0 |
| 350-400 | 50 | 8400 | 610 | 1.115 | 11,600 | 428 | 640 | 501 | 22.4 |
| 400-450 | 50 | 11200 | 772 | 1.110 | 8,800 | 325 | 500 | 500 | 22.4 |
| 450-500 | 50 | 14200 | 945 | 1.103 | 5,800 | 215 | 346 | 486 | 22.0 |
| 500-510 | 10 | 16200 | 1065 | 1.02 | 3,800 | 141 | 235 | 480 | 21.9 |
| 510-550 | 40 | 16900 | 1105 | 1.081 | 3,100 | 116 | 194 | 458 | 21.4 |
| 550-600 | 50 | 17300 | 1135 | 1.096 | 2,700 | 100 | 168 | 432 | 20.8 |
| 600-650 | 50 | 17700 | 1148 | 1.101 | 2,300 | 86 | 143 | 405 | 20.1 |
| 650-700 | 50 | 18050 | 1150 | 1.100 | 1,950 | 73 | 122 | 380 | 19.5 |
| 700-750 | 50 | 18450 | 1135 | 1.103 | 1,550 | 58 | 95 | 352 | 18.8 |
| 750-800 | 50 | 18850 | 1085 | 1.110 | 1,150 | 43 | 65 | 325 | 18.0 |
| 800-830 | 30 | 19100 | 1055 | 1.071 | 900 | -15 | -21 | 300 | 17.3 |
| 830-860 | 30 | 19400 | 1000 | 1.076 | 600 | -79 | -110 | 271 | 16.5 |
| 860-890 | 30 | 19600 | 980 | 1.078 | 400 | -135 | -183 | 238 | 15.4 |
| 890-920 | 30 | 19850 | 945 | 1.080 | 150 | -193 | -246 | 201 | 14.2 |
| 920-950 | 30 | 20000 | 910 | 1.083 | 0 | -250 | -310 | 161 | 12.7 |
| 950-1000 | 50 | 20000 | 910 | 1.138 | 0 | -250 | -310 | 105 | 10.2 |
| 1000-1050 | 50 | 20000 | 910 | 1.138 | 0 | -250 | -310 | 55 | 7.4 |
| 1050-1100 | 50 | 20000 | 910 | 1.138 | 0 | -250 | -310 | 10 | 3.2 |
| 1100-1150 | 50 | 20000 | 910 | 1.138 | 0 | -250 | -310 | -29 | - |
| 1150-1200 | 50 | 20000 | 910 | 1.138 | 0 | -250 | -310 | -29 | - |

W = 20,000 Tons
10 Drags - 50 Tons each
$f_g$ = 0.010
$f_d$ = 0.500

Total Travel = 1113 Feet

## TABLE II

### Calculating Machine and Slide Rule Method

### For Determination of Ultimate Travel

| Increment No. | (1) Travel | (2) $S$ (Increment) | (3) $B$ Buoyancy (Average) | (4) $(W-B)$ | (5) $(W-B) \times \sin\theta$ | (6) $f_g(W-B)$ | (7) Drag Force |
|---|---|---|---|---|---|---|---|
| 1 | 0-50 | 50 | 200 | 19,800 | 927 | 198 | 0 |
| 2 | 50-100 | 50 | 325 | 19,675 | 921.2 | 196.8 | 0 |
| 3 | 100-150 | 50 | 650 | 19,350 | 906 | 193.5 | 0 |
| 4 | 150-200 | 50 | 1,300 | 18,700 | 875.5 | 187 | 0 |
| 5 | 200-250 | 50 | 2,500 | 17,500 | 819.3 | 175 | 0 |
| 6 | 250-300 | 50 | 4,100 | 15,900 | 744.4 | 159 | 0 |
| 7 | 300-350 | 50 | 6,100 | 13,900 | 650.8 | 139 | 0 |
| 8 | 350-400 | 50 | 8,400 | 11,600 | 543.1 | 116 | 0 |
| 9 | 400-450 | 50 | 11,200 | 8,800 | 412 | 88 | 0 |
| 10 | 450-500 | 50 | 14,200 | 5,800 | 271.6 | 58 | 0 |
| 11 | 500-510 | 10 | 16,200 | 3,800 | 177.9 | 38 | 0 |
| 12 | 510-550 | 40 | 16,900 | 3,100 | 145.1 | 31 | 0 |
| 13 | 550-600 | 50 | 17,300 | 2,700 | 126.4 | 27 | 0 |
| 14 | 600-650 | 50 | 17,700 | 2,300 | 107.7 | 23 | 0 |
| 15 | 650-700 | 50 | 18,050 | 1,950 | 91.3 | 19.5 | 0 |
| 16 | 700-750 | 50 | 18,450 | 1,550 | 72.6 | 15.5 | 0 |
| 17 | 750-800 | 50 | 18,850 | 1,150 | 53.8 | 11.5 | 0 |
| 18 | 800-830 | 30 | 19,100 | 900 | 42.1 | 9 | 50 |
| 19 | 830-860 | 30 | 19,400 | 600 | 28.1 | 6 | 100 |
| 20 | 860-890 | 30 | 19,600 | 400 | 18.7 | 4 | 150 |
| 21 | 890-920 | 30 | 19,850 | 150 | 7.0 | 1.5 | 200 |
| 22 | 920-950 | 30 | 20,000 | 0 | 0 | 0 | 250 |
| 23 | 950-1000 | 50 | 20,000 | 0 | 0 | 0 | 250 |
| 24 | 1000-1050 | 50 | 20,000 | 0 | 0 | 0 | 250 |
| 25 | 1050-1100 | 50 | 20,000 | 0 | 0 | 0 | 250 |
| 26 | 1100-1150 | 50 | 20,000 | 0 | 0 | 0 | 250 |
| 27 | 1150-1200 | 50 | 20,000 | 0 | 0 | 0 | 250 |

## TABLE II, CONT'D.

Calculating Machine and Slide Rule Method

For Determination of Ultimate Travel

| Increment No. | (8) $F_1$ Net Force | (9) %B Afloat | (10) $B^{2/3}$ | (11) C Keith's Coeff. | (12) $\frac{B^{2/3}}{C}$ | (13) $Q = \frac{2B^{2/3}gS}{WC}$ | (14) $e^Q$ | (15) $\frac{1}{e^Q}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 729 | 1 | 34.2 | 28 | 1.221 | 0.1964 | 1.218 | 0.821 |
| 2 | 724.4 | 1.63 | 47.2 | 47 | 1.003 | 0.1615 | 1.175 | 0.850 |
| 3 | 712.5 | 3.25 | 75 | 86 | 0.872 | 0.1405 | 1.150 | 0.870 |
| 4 | 688.5 | 7.5 | 119 | 160 | 0.744 | 0.1198 | 1.127 | 0.887 |
| 5 | 644.3 | 12.5 | 185 | 260 | 0.712 | 0.1146 | 1.121 | 0.892 |
| 6 | 585.4 | 20.5 | 258 | 355 | 0.727 | 0.1170 | 1.124 | 0.890 |
| 7 | 511.8 | 30.5 | 332 | 475 | 0.699 | 0.1125 | 1.128 | 0.887 |
| 8 | 427.1 | 42 | 412 | 610 | 0.675 | 0.1087 | 1.115 | 0.897 |
| 9 | 324 | 56 | 500 | 772 | 0.648 | 0.1043 | 1.110 | 0.901 |
| 10 | 213.6 | 71 | 585 | 945 | 0.619 | 0.0997 | 1.105 | 0.905 |
| 11 | 139.9 | 81 | 640 | 1065 | 0.601 | 0.0194 | 1.020 | 0.981 |
| 12 | 114.1 | 84.5 | 660 | 1105 | 0.597 | 0.0769 | 1.080 | 0.926 |
| 13 | 99.4 | 86.5 | 675 | 1135 | 0.595 | 0.0958 | 1.101 | 0.909 |
| 14 | 84.7 | 88.5 | 685 | 1148 | 0.597 | 0.0961 | 1.101 | 0.903 |
| 15 | 71.8 | 90.3 | 690 | 1150 | 0.600 | 0.0966 | 1.102 | 0.908 |
| 16 | 57.1 | 92.3 | 700 | 1135 | 0.617 | 0.0993 | 1.105 | 0.905 |
| 17 | 42.3 | 94.3 | 705 | 1085 | 0.650 | 0.1047 | 1.110 | 0.901 |
| 18 | -16.9 | 95.5 | 710 | 1055 | 0.673 | 0.0650 | 1.067 | 0.937 |
| 19 | -77.9 | 97 | 720 | 1000 | 0.720 | 0.0696 | 1.072 | 0.933 |
| 20 | -135.3 | 98 | 730 | 980 | 0.745 | 0.0720 | 1.075 | 0.930 |
| 21 | -194.7 | 99.3 | 735 | 945 | 0.778 | 0.0752 | 1.078 | 0.928 |
| 22 | -250 | 100 | 740 | 910 | 0.813 | 0.0785 | 1.082 | 0.924 |
| 23 | -250 | 100 | 740 | 910 | 0.813 | 0.1309 | 1.140 | 0.877 |
| 24 | -250 | 100 | 740 | 910 | 0.813 | 0.1309 | 1.140 | 0.877 |
| 25 | -250 | 100 | 740 | 910 | 0.813 | 0.1309 | 1.140 | 0.877 |
| 26 | -250 | 100 | 740 | 910 | 0.813 | 0.1309 | 1.140 | 0.877 |
| 27 | -250 | 100 | 740 | 910 | 0.813 | 0.1309 | 1.140 | 0.877 |

## TABLE. II, CONT'D

### Calculating Machine and Slide Rule Method

### For Determination of Ultimate Travel

| INCREMENT No. | (16)<br>$e^Q-1$ | (17)<br>$\frac{C}{B^{2/3}}$ | (18)<br>$\frac{CF_1}{B^{2/3}}$ | (19)<br>$\frac{CF_1(e^Q-1)}{B^{2/3}}$ | (20)<br>$V_1^2+\frac{CF_1(e^Q-1)}{B^{2/3}}$<br>(21) From Line<br>Above (19) | (21)<br>$V_2^2=\frac{1}{e^Q}\left[V_1^2+\frac{CF_1(e^Q-1)}{B^{2/3}}\right]$ | (22)<br>$V_2$ |
|---|---|---|---|---|---|---|---|
| 1 | .218 | .819 | 597 | 130.1 | 130.1 | 106.8 | 10.3 |
| 2 | .175 | .998 | 720 | 126 | 232.8 | 197.9 | 14.1 |
| 3 | .150 | 1.147 | 817 | 122.6 | 320.5 | 279 | 16.7 |
| 4 | .127 | 1.343 | 925 | 117.5 | 396.5 | 351.7 | 18.8 |
| 5 | .121 | 1.405 | 905 | 109.5 | 461.2 | 411.4 | 20.3 |
| 6 | .124 | 1.375 | 805 | 99.8 | 511.2 | 455 | 21.3 |
| 7 | .128 | 1.430 | 732 | 93.7 | 548.7 | 486.7 | 22.1 |
| 8 | .115 | 1.482 | 633 | 72.8 | 559.5 | 501.9 | 22.4 |
| 9 | .110 | 1.542 | 500 | 55 | 556.9 | 501.8 | 22.4 |
| 10 | .105 | 1.615 | 345 | 36.2 | 538 | 486.9 | 22.1 |
| 11 | .0195 | 1.665 | 233 | 4.5 | 491.4 | 482.1 | 21.9 |
| 12 | .080 | 1.678 | 191 | 15.3 | 497.4 | 460.6 | 21.4 |
| 13 | .1005 | 1.680 | 167 | 16.8 | 477.4 | 434.0 | 20.8 |
| 14 | .101 | 1.680 | 142 | 14.3 | 448.3 | 407.0 | 20.2 |
| 15 | .1015 | 1.667 | 120 | 12.2 | 419.2 | 380.6 | 19.5 |
| 16 | .1045 | 1.622 | 93 | 9.7 | 390.3 | 351.7 | 18.8 |
| 17 | .110 | 1.538 | 65 | 7.2 | 358.9 | 323.4 | 18.0 |
| 18 | .067 | 1.485 | -25.1 | -1.7 | 321.7 | 301.4 | 17.3 |
| 19 | .072 | 1.390 | -108 | -7.8 | 293.6 | 273.9 | 16.6 |
| 20 | .075 | 1.342 | -182 | -13.7 | 260.2 | 242 | 15.5 |
| 21 | .078 | 1.285 | -250 | -19.5 | 222.5 | 206.5 | 14.3 |
| 22 | .082 | 1.229 | -307 | -25.2 | 181.3 | 167.5 | 12.9 |
| 23 | .140 | 1.229 | -307 | -43.0 | 124.5 | 109.2 | 10.4 |
| 24 | .140 | 1.229 | -307 | -43.0 | 66.2 | 58.1 | 7.6 |
| 25 | .140 | 1.229 | -307 | -43.0 | 15.1 | 13.2 | 3.6 |
| 26 | .140 | 1.229 | -307 | -43.0 | -27.9 | -24.5 | - |
| 27 | .140 | 1.229 | -307 | -43.0 | -27.9 | -24.5 | - |

$W$ = 20,000 Tons

10 Drags - 50 Tons each

Total Travel - 1117 Feet

$f_g$ = 0.010

$f_d$ = 0.500

## Sources of Data for Analysis

The data on which the analyses of the variation of travel with different variables were based was collected at the Norfolk Naval Shipyard at the time of launching the USS SHANGRI-LA (CV38), which used seven clumps per side and the USS TARAWA (CV40), with five clumps per side. Hydraulic dynamometers were placed in six of the wires connecting the drag chain clumps to the vessel. The drags passed over three surfaces, rough concrete composed of concrete bearers with about six feet of soft earth between them, smooth slab concrete, and steel which covered the trigger pit. Tables III and IV are enclosed herewith, giving a summary of data taken from these dynamometers. Each clump weighed 50 tons.

Table V is a summary of the conditions at the time of launching of these vessels. Tables III, IV, and V, it is felt, fully justify the values of the different variables used in this thesis report. The ranges of the variables were selected from values referred to in the published literature on the subject.

For reference, the observed launching velocities of the USS SHANGRI-LA and USS TARAWA are shown in Curve VII as computed in the Norfolk Naval Shipyard.

## TABLE III

### USS SHANGRI-LA-CV38

### Chain Drag Dynamometer Data

| Drag No. | Energy Absorbed Ft.-Lb. | Effective Distance Ft. | $Df_d$ Average | $f_b$ Average |
|---|---|---|---|---|
| **Rough Concrete** | | | | |
| 1 Port | 16,464,000 | 282 | 58,383 | 0.521 |
| 1 Stbd | 17,428,000 | 282 | 61,801 | 0.552 |
| 3 Port | 14,060,000 | 230 | 61,130 | 0.546 |
| 3 Stbd | 14,432,000 | 230 | 62,748 | 0.560 |
| 6 Port | 2,720,000 | 52 | 52,307 | 0.467 |
| 6 Stbd | 3,084,000 | 52 | 59,307 | 0.530 |
| Totals | 68,188,000 | 1,128 | 60,450 | 0.540 |
| **Smooth Concrete** | | | | |
| 1 Port | 0 | 0 | 0 | 0 |
| 1 Stbd | 0 | 0 | 0 | 0 |
| 3 Port | 0 | 0 | 0 | 0 |
| 3 Stbd | 0 | 0 | 0 | 0 |
| 6 Port | 4,152,000 | 123 | 33,756 | 0.301 |
| 6 Stbd | 4,420,000 | 123 | 35,935 | 0.321 |
| Totals | 8,572,000 | 246 | 34,846 | 0.311 |
| **Steel Cover of Trigger Pit** | | | | |
| 1 Port | 558,000 | 25 | 22,320 | 0.199 |
| 1 Stbd | 608,000 | 25 | 26,720 | 0.239 |
| 3 Port | 580,000 | 25 | 23,200 | 0.207 |
| 3 Stbd | 584,000 | 25 | 23,360 | 0.209 |
| 6 Port | 0 | 0 | 0 | 0 |
| 6 Stbd | 0 | 0 | 0 | 0 |
| Totals | 2,390,000 | 100 | 23,900 | 0.213 |

# TABLE IV

## USS TARAWA -CV38

## Chain Drag Dynamometer Data

### Rough Concrete

| Drag No. | Energy Absorbed Ft.-Lb. | Effective Distance Ft. | $Df_d$ Average | $f_g$ Average |
|---|---|---|---|---|
| 1 Port | 23,610,000 | 389 | 60,700 | 0.542 |
| 1 Stbd | 24,020,000 | 389 | 61,600 | 0.551 |
| 2 Port | 19,800,000 | 315 | 62,900 | 0.562 |
| 2 Stbd | 19,420,000 | 315 | 61,600 | 0.551 |
| 4 Port | 9,150,000 | 173 | 53,000 | 0.473 |
| 4 Stbd | 9,540,000 | 173 | 55,150 | 0.492 |
| Totals | 105,540,000 | 1,754 | 60,200 | 0.537 |

### Smooth Concrete

| Drag No. | Energy Absorbed Ft.-Lb. | Effective Distance Ft. | $Df_d$ Average | $f_g$ Average |
|---|---|---|---|---|
| 1 Port | 0 | 0 | 0 | 0 |
| 1 Stbd | 0 | 0 | 0 | 0 |
| 2 Port | 1,576,000 | 32 | 49,300 | 0.440 |
| 2 Stbd | 1,389,000 | 32 | 43,400 | 0.387 |
| 4 Port | 3,740,000 | 116 | 32,250 | 0.288 |
| 4 Stbd | 3,935,000 | 116 | 33,920 | 0.303 |
| Totals | 10,640,000 | 296 | 35,960 | 0.321 |

### Steel Cover of Trigger Pit

| Drag No. | Energy Absorbed Ft.-Lb. | Effective Distance Ft. | $Df_d$ Average | $f_g$ Average |
|---|---|---|---|---|
| 1 Port | 892,500 | 28 | 31,900 | 0.284 |
| 1 Stbd | 873,000 | 28 | 31,200 | 0.278 |
| 2 Port | 845,000 | 28 | 30,150 | 0.269 |
| 2 Stbd | 925,000 | 28 | 33,060 | 0.295 |
| 4 Port | 740,000 | 28 | 26,410 | 0.236 |
| 4 Stbd | 838,000 | 28 | 29,900 | 0.267 |
| Totals | 5,113,500 | 168 | 30,400 | 0.272 |

## TABLE V

USS SHANGRI-LA Launching

OBSERVED DATA

| | | |
|---|---|---|
| Launching Wt. (Ship & Cradle) Tons | | 21088 |
| C. G. Ship & Cradle Aft. of M. P. | | 14.32 |
| Draft, Forward | Ft. & In. | 14-1-7/8 |
| Draft, Aft | Ft. & In. | 21-11 |
| Draft, Mean | Ft. & In. | 18-0 7/16 |
| Depth of Water Over Way Ends Ft. | | 15.86 |
| Average Initial Pressure | Tons/Sq. Ft. | 2.10 |
| Travel to Pivot | Ft. | 527 |
| Pivoting Pressure | Tons | 4140 |
| Maximum Way End Pressure | Tons/Sq. Ft. | 3.40 |
| Travel to Maximum W. E. Pressure (Ft.) | | 320 |
| Coefficient of Friction of Grease | | .012 |
| Coefficient of Friction of Concrete | | .311 |
| Coefficient of Friction Concrete Bearers and Gravel | | .540 |
| Coefficient of Friction Steel | | .212 |
| Keith's Coefficient of Water Resistance at 100% Buoyancy | | 1400 |
| Maximum Velocity | Ft./Sec. | 22.15 |
| Travel to Max. Velocity | Ft. | 390 |
| Drop-Off Velocity | Ft./Sec. | 15.3 |
| Travel to Stop | Ft. | 1110 |
| Stern to Opposite Shore | | 544 |
| F. P. from W. E. | | 197 |

## TABLE V, CONT'D

### GENERAL INFORMATION

### Dimensions of Vessel

| | |
|---|---|
| Length between Perpendiculars | 820'-0" |
| Length Over All | 888' - 9-1/8" |
| Beam, molded | 93' - 0" |
| Breadth, Flight Deck | 109' - 0" |
| Dead Rise | 0' - 9" |
| Designer's L.W.L. (Above Bottom of Keel) | 26' - 7-7/8" |
| Displacement (Designers L.W.L.) | 33,500 Tons |
| Midship Section | Frame 102½ |
| Frame Spacing | 4' - 0" |

### Blocking

| | |
|---|---|
| Type of Blocks | Collapsible |
| Material of Blocks | White Oak |
| Minimum Height | 5' - 0" above 9/16" Declivity Line |
| Declivity of Keel | 9/16" |

### Ground Ways

| | |
|---|---|
| Length of Ground Ways, Over All | 890' - 0" |
| Length of Ground Ways, from Face of Jack Log to Ways End | 874' - 3" |
| Length of Ground Ways from Face of Jack Log to Face of Trigger | 470' - 9" |
| Length of Ground Ways from Face of Trigger to End of Ways | 403' - 6" |
| Declivity of Ways | 9/16"/Ft. |
| Transverse Slope of Ways | 3/8"/Ft. |
| Width of Ground Ways | 7' - 2" |
| Material of Ground Ways | Long Leaf Yellow Pine |
| Spread of Ground Ways C to C | 26' - 0" |
| Spread of Ground Ways R to R | 33' - 2" |

### Sliding Ways

| | |
|---|---|
| Forward End of Sliding Ways | Frame 7 |
| After End of Sliding Ways | Frame 186½ |
| Length of Sliding Ways, Over All | 718' - 3½" |
| Length of Sliding Ways, Effective | 716' - 0" |
| Length of Sliding Ways Forward of Trigger | 467' - 2" |

## TABLE V, CONT'D

### Sliding Ways Cont'd.

| | |
|---|---|
| Length of Sliding Ways Aft of Trigger | 251' - 1½" |
| Width of Sliding Ways, Total | 7' - 2" |
| Width of Sliding Ways, Effective | 7' - 0" |
| Space Between Sliding Way and Ribband | 1½" |
| Bearing Area Sliding Ways, Effective | 10024 sq. ft. |
| Wedges, Number | 726 |
| Wedge Material | Oak |
| Wedge, Average Load Per | 29.0 Tons |
| Grease Irons, Number | 146 |
| Grease Irons, Type | Steel, tapered |
| Grease Irons, Average Load Per | 6.3 Tons. |

### Lubrication of Ways

| | | |
|---|---|---|
| (a) | Base Coat | Keystone, ½" thick |
| (b) | Slip Coat | Keystone, ¼" thick |
| (c) | Amount of Base Coat Applied | 30,000# |
| (d) | Amount of Slip Coat Applied | 15,600# |
| (e) | Amount of Base Coat Recovered | 23,383# |
| (f) | Amount of Slip Coat Recovered | 0 |

# BIBLIOGRAPHY

1. Rossell and Chapman,

   PRINCIPLES OF NAVAL ARCHITECTURE.

   Volume I, Chapter VII, Page 250 - 284.

2. T. C. Tobin,

   "Dynamics of Launching."

   Shipbuilding and Shipping Record, Vol. 65, No. 20, May 17, 1945,

   Page 471-4.

3. C. R. Nevitt and A. R. Anderson

   "Two Aspects of the Dynamic Launching Problem".

   Paper before: N. E. Coast Institute of Engineers and Shipbuilders,

   Vol. 62, Page 361 - 382.

4. H. B. Andrews and A. M. Nickerson

   "Some Practical Aspects of Ship Launching".

   Paper before: Society of Naval Architects and Marine Engineers,

   New England Section, October 1945.

5. A. See

   "Launching of the NORMANDIE"

   Transactions of the Society of Naval Architects and Marine

   Engineers, 1933, Page 316 - 340.

6. J. M. McNeill,

   "Launch of the Quadruple Screw Turbine Steamer QUEEN MARY"

   Institution of Naval Architects, 1935, Page 1 - 27.

7. E. H. Rigg,
"Launch of the Airplane Carrier USS SARATOGA"
Transactions of the Society of Naval Architects and Marine Engineers, 1925, Page 147 - 160.

8. S. W. Wakeman,
"Launch of the Airplane Carrier USS LEXINGTON".
Transactions of the Society of Naval Architects and Marine Engineers, 1926, Page 139 - 161.

9. E. E. Russell,
"A Determination of the Coefficient of Resistance of the Chain Drags for the Launching of USS LEXINGTON".
Thesis, Massachusetts Institute of Technology, 1924.

10. Huske and Magruder,
"Analysis of Launching by Model Experiment".
Thesis, Massachusetts Institute of Technology, 1926.

11. Ingram and Whitgrove,
"Analysis of Launching of USS LEXINGTON".
Thesis, Massachusetts Institute of Technology, 1927.

12. H. M. Gleason and H. E. Saunders,
"Launching of Ships in Restricted Waters".
Transactions of the Society of Naval Architects and Marine Engineers, 1919, Page 201 - 214.

13. S. R. Heller, Jr., and R. H. Slaughter, Jr.,
"Launching Large Vessels in Restricted Waters--USS SHANGRI-LA, USS TARAWA".

Paper before: Chesapeake Section, Society of Naval Architects
and Marine Engineers. March, 1947.

14. A. J. Chantry,
"Launching of USS NEW JERSEY and USS WISCONSIN"
Society of Naval Architects and Marine Engineers, Transactions,
Vol. 52, 1944, Page 391 - 431, (discussion) 431-8

15. C. & R. Bulletin
"Launching of USS CALIFORNIA - OMAHA"
Bulletin 16, of May 1921.

16. William Denny,
"Launching Velocities"
Institution of Naval Architects, 1882, Page 99 - 111

17. CV38 - Preliminary Launching Curves
Bureau of Ships Plan Number CV38-S0602-297027

18. Actual Launching Curves
Bureau of Ships Plan Number CV38-S0602-301713

19. CV38 - Curves Obtained from Launching Observation Data
Bureau of Ships Plan Number CV38-S0602-301714

20. Launching Day Tide Curve
Bureau of Ships Plan Number CV38-S0601-299506

21. Launching Day Tide Curve
Bureau of Ships Plan Number CV40-S0601-633095

22. Plot of Observed Tension in Chain Drag Cables
No. 1, 3, and 6 Port and Starboard
Bureau of Ships Plan Number CV38-S0602-301715

23. Plot of Estimated Tension in Chain Drag Cables

Bureau of Ships Plan Number CV38-S0602-301716

24. General Launching Arrangement

Bureau of Ships Plan Number CV38-S0601-296331

25. Douglass and Adams

ELEMENTS OF NOMOGRAPHY

26. Alcock and Jones

THE NOMOGRAM

27. Joseph Lipka

GRAPHICAL AND MECHANICAL COMPUTATION

28 C. O. Mackey

GRAPHICAL SOLUTIONS

AUG 31 BINDERY

Thesis 6932
R8 Rourke

AUTHOR
An investigation of the relative importance of those variables affecting the travel of a vessel at launching
TITLE

| DATE LOANED | BORROWER'S NAME | DATE RETURNED |
|---|---|---|
| | | |
| | | |
| | | |

Thesis 6932
R8 Rourke
An investigation of the relative importance of those variables affecting the travel of a vessel at launching.

ARTISAN
GOLD LETTERING
AND
SMITH BINDERY
OAKLAND, CALIF.

thesR8
An investigation of the relative importa
3 2768 001 97055 1
DUDLEY KNOX LIBRARY